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TECHNICAL MEMORANDUM TM-1263

TEA - 2

TRAJECTORY ERROR ANALYSIS  
COMPUTER PROGRAM  
FOR  
TWO-DEGREE OF FREEDOM TRAJECTORIES

BY

HAROLD J. KOPP

JOHN N. NIELSEN

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for Two-Degree of Freedom Trajectories

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Harold J. Kopp  
John N. Nielsen

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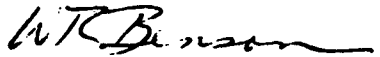
Reviewed by:



JOSEPH SPECTOR

Chief, Computing and Analysis Section

Approved by:



W. R. BENSON

Chief, Engineering Sciences Laboratory

FELTMAN RESEARCH LABORATORIES  
PICATINNY ARSENAL, DOVER, N. J.

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## ABSTRACT

Estimates of the cumulative error associated with the third-order Runge-Kutta solution of the two-degree of freedom equations of motion are presented. These estimates constitute a simple, but not rigorous, approach to automatic increment selection. Details of the computer program TEA-2 which utilize these equations are described. Sample calculations are included. TEA-2 is between 2.0 and 1.7 times faster than the previous trajectory program in addition to providing greater consistency and reliability.

## INTRODUCTION

Numerical solutions of two-degree of freedom trajectory problems are approximations to the exact solutions. Intelligent and efficient employment of high-speed computers for solving these trajectory problems requires that the errors resulting from numerical methods be controlled. This report presents the equations and describes the computer techniques used in TEA-2, a computer program which calculates integration step length automatically. The integration step length is computed such that the estimated error in the range and/or percentage error in altitude at impact compared to maximum altitude lies within prescribed limits. This program, therefore, provides ammunition designers with the ability to calculate trajectories such that the cumulative numerical error at the impact point is tolerable and of pre-specified magnitude.

The TEA-2 trajectory program requires the usual input of drag, thrust, and mass tables as well as initial conditions for velocity, angle, and the coordinate position. In addition, one must furnish allowable percentage errors for the range and/or maximum altitude. Details concerning input and output are included in Section C of the Procedure.

Equations for error estimation and automatic step selection are presented in Section A. Program limitations and computer flow are described in Section B. Appendix I contains a FORTRAN listing of the program. Lastly, sample calculations are presented in Appendix II.

## PROCEDURE

A previous report, Technical Memorandum 1262, established a rigorous mathematical foundation for this work. Results from that report are utilized in conjunction with additional approximations to provide a set of equations for TEA-2. Section A contains this aspect of the analysis. The general features of TEA-2 and detailed instructions for its application are presented in Sections B and C, respectively.

### A. Mathematical Basis

Trajectory equations of motion for a point-mass, two-degree of freedom system are:

$$\begin{aligned}\dot{X} &= V \cos \theta & X(t=0) &= 0 \\ \dot{Y} &= V \sin \theta & Y(t=0) &= Y_0 \\ \dot{V} &= \frac{T}{m} - g \sin \theta - \rho K_D d^2 V^2 / m & V(t=0) &= V_0 \\ \dot{\theta} &= -g \cos \theta / V & \theta(t=0) &= \theta_0\end{aligned}\tag{1}$$

where  $T(t)$ ,  $m(t)$ ,  $\rho(y)$ ,  $K_D(V, \theta)$ ,  $g(y)$ , and  $d$  are given. They symbolize thrust, mass, air density, the drag coefficient, gravitational acceleration, and particle diameter, respectively. The quantities  $V$  and  $\theta$  are the magnitude and orientation of the particle velocity, respectively. Particle position coordinates are specified by  $x$  and  $y$ . Figure 1 illustrates these quantities.

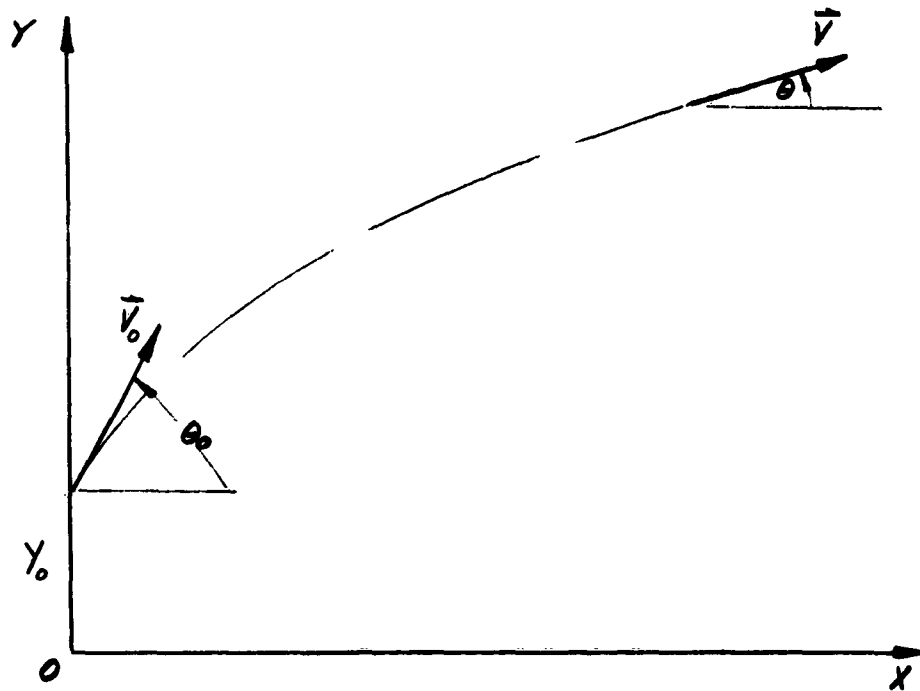


Figure 1  
The Coordinate System

An approximate solution to the set of equations (1) is obtained by using a third-order Runge-Kutta method. The approximate solution is given by:

$$U_{i+1} = U_i + c_1 K_{1U} + c_2 K_{2U} + c_3 K_{3U} \quad U = x, y, v, \theta \quad (2)$$

where

$$K_{1U} = h \dot{U}(x_i, y_i, v_i, \theta_i, t_i) \quad (3)$$

$$K_{2U} = h \dot{U}(x_i + c_1 K_{1x}, y_i + c_1 K_{1y}, v_i + c_1 K_{1v}, \theta_i + c_1 K_{1\theta}, t_i + c_1 h)$$

$$K_{3U} = h \dot{U}(x_i + c_1 K_{1x} + c_2 K_{2x}, \dots, t_i + c_1 h + c_2 h)$$



Coefficients corresponding to the Gill modification are used. They are:

$$C_1 = .62653829$$

$$C_2 = -.55111241$$

$$C_4 = -.48268182$$

$$C_5 = .85614329$$

Application of the Runge-Kutta solution method to equations (1) introduces truncation error which is dependent on the degree of approximation and rounding error which follows from the limitations of the digital computer. Errors at the  $i$ -th time step propagate forward in time and introduce "propagation error."

The aforementioned errors were treated at length in TM-1262. It was shown that a bound for the cumulative error can be obtained from consideration of propagation, truncation, and rounding errors. Results from TM-1262 are combined with assumptions and approximations in this section. The set of equations so derived provide estimates of the cumulative error (not rigorous error bounds), and is employed in the TEA-2 program. The assumptions, limitations, and equations used in TEA-2 follow.

Assumptions:

1. The speed of the point-mass does not change by more than 5% per time increment.
2. The orientation of the velocity vector does not change by more than 2 degrees per time increment.
3. The difference between the values generated by a single step of length  $(h)$  and two steps of length  $\frac{h}{2}$  is only due to truncation and rounding errors.
4. Quantities undergoing arithmetic operations and those in storage possess a relative error less than  $10^{-8}$ .
5. Sine and cosine routines used on the Picatinny Arsenal IBM 709 have a relative error less than  $10^{-8}$ .

Derivations contained in TM-1262 established rigorous error bounds. This report is not concerned with rigorous error bounds, but with error estimates. Consequently, bounding values for the variables used in TM-1262 will be replaced by local values. Moreover, estimates for truncation error based upon the difference in the variables for a single step of length (h) and two steps of length (h/2) will be employed. Appropriately modified equations from TM-1262 follow. Estimates of cumulative errors at the i-th point which result from errors at the n-th point are:

$$e_{vi} = V \left[ -c_1 + (c_1 + c_2) \lambda_1^{i-n} \right] \quad (4)$$

$$e_{\theta i} = \frac{|K|}{V} e_{vi} \quad (5)$$

$$e_{xi} = e_{xn} + Vh \left[ (i-n)(\alpha_{xT} h^3 + \alpha_{xR}) - c_1' c_3' + (c_1' + c_2') c_3' \frac{\lambda_1^{i-n} - 1}{\lambda_1 - 1} \right] \quad (6)$$

$$e_{yi} = e_{yn} + Vh \left[ (i-n)(\alpha_{yT} h^3 + \alpha_{yR}) - c_1' c_4' + (c_1' + c_2') c_4' \frac{\lambda_1^{i-n} - 1}{\lambda_1 - 1} \right] \quad (7)$$

where

$$c_2' = \max \left\langle \frac{e_{vn}}{V}, \frac{e_{\theta n}}{|K|} \right\rangle \quad (8)$$

$$c_3' = \alpha_{13} + K \alpha_{14} \quad (9)$$

$$c_4' = \alpha_{23} + K \alpha_{24} \quad (10)$$

$$c_1' = \frac{1}{|\Delta_1|} \max \left\langle |\bar{\phi} h^3 + \bar{\phi}|, |\bar{\psi} h^3 + \bar{\psi}| \right\rangle \quad (11)$$

$$\text{and } \bar{\phi} = \alpha_{44} \alpha_{VT} - \alpha_{34} \alpha_{\theta T}$$

$$\bar{\phi} = \alpha_{44} \alpha_{VR} - \alpha_{34} \alpha_{\theta R}$$

(12)

$$\bar{\psi} = -\alpha_{43} \alpha_{VT} + \alpha_{32} \alpha_{\theta T}$$

$$\bar{\psi} = -\alpha_{43} \alpha_{VR} + \alpha_{32} \alpha_{\theta R}$$

also,

$$K = \frac{\epsilon - \alpha_{33}}{\alpha_{34}} \quad (13)$$

$$\epsilon = \frac{1}{2} \left[ \alpha_{33} + \alpha_{44} + \sqrt{(\alpha_{33} - \alpha_{44})^2 + 4\alpha_{34}\alpha_{43}} \right] \quad (14)$$

$$\lambda_1 = 1 + \sigma \epsilon h \quad (15)$$

$$\Delta_1 = \alpha_{33} \alpha_{44} - \alpha_{34} \alpha_{43}, \quad \sigma = \frac{g}{V} \quad (16, 17)$$

The propagation error coefficients are given by:

$$\rho_c = \cos \theta, \quad \rho_s = |\sin \theta| \quad (18)$$

$$\alpha_{13} = \rho_c (1.03 - .014c + .0003c^2) \quad (19.1)$$

$$\alpha_{14} = 1.20 \rho_s + 0.28 - .0001c \quad (19.2)$$

$$\alpha_{23} = (\rho_s + .08)(1.0 - .02c + .0004c^2) + .10 \quad (19.3)$$

$$\alpha_{24} = (\rho_c + .07, \alpha_{44} \quad (19.4)$$

$$\alpha_{33} = .019 - 1.10c + .04c^2 - .0002c^3 \quad (19.5)$$

$$\alpha_{34} = (\rho_c + .10)(1.02 + .018c) \quad (19.6)$$

$$\alpha_{43} = (\rho_c + .07)(1.40 - .02c + .0003c^2) \quad (19.7)$$

$$\alpha_{44} = 1.20 \rho_s + .21 + .003c \quad (19.8)$$

$$\text{where } c = \frac{2\rho K_D d^2 V^2}{mg} \quad (20)$$

Next, one invokes the assumption that the difference between the values resulting from a single step of length (h) and two steps of length (h/2) is only due to truncation and rounding errors. Subtraction of the rounding error yields:

$$\Delta x = \max \langle |x(h) - x(2 \cdot \frac{h}{2})| - \alpha_{xR} h V, 0 \rangle \quad (21.1)$$

$$\Delta y = \max \langle |y(h) - y(2 \cdot \frac{h}{2})| - \alpha_{yR} h V, 0 \rangle \quad (21.2)$$

$$\Delta V = \max \langle |V(h) - V(2 \cdot \frac{h}{2})| - \alpha_{VR} g h, 0 \rangle \quad (21.3)$$

$$\Delta \theta = \max \langle |\theta(h) - \theta(2 \cdot \frac{h}{2})| - \alpha_{\theta R} \frac{h g}{V}, 0 \rangle \quad (21.4)$$

where the rounding error coefficients may be approximated by:

$$\begin{aligned} \alpha_{xR} &= 1.9 \times 10^{-7} \\ \alpha_{yR} &= 1.9 \times 10^{-7} \\ \alpha_{VR} &= \left[ 2.9 \frac{I}{mg} + 2.0 + 2.3 C \right] \times 10^{-7} \\ \alpha_{\theta R} &= 2.6 \times 10^{-7} \end{aligned} \quad (22)$$

It follows from equations (15), (23), (92), (93), (94), and (95) of FRL-TM-1262 that

$$\Delta V \approx \frac{7}{4} \left| \frac{\bar{\phi}}{\Delta_1} \right| h^3 \quad (23)$$

$$\Delta \theta \approx \frac{7}{4} \left| \frac{\bar{x}}{\Delta_1} \right| h^3 \quad (24)$$

Thus,

$$\alpha_{VT} \approx (|\alpha_{33}| \Delta V + \alpha_{34} V \Delta \theta) \frac{4 |\Delta_1|}{7 V h^3} \quad (25)$$

$$\alpha_{\theta T} \approx (|\alpha_{43}| \Delta V + \alpha_{44} V \Delta \theta) \frac{4 |\Delta_1|}{7 V h^3} \quad (26)$$

Also,

$$\alpha_{xT} \approx \frac{8 \Delta x}{7 V h^4} \quad (27)$$

$$\alpha_{yT} \approx \frac{8 \Delta y}{7 V h^4} \quad (27.1)$$

Time increments are selected such that the estimated cumulative errors based upon local (that is, n-th step) propagation, truncation, and rounding errors satisfy specified allowable error criteria for the x and/or y variables at the impact point. That is,

$$\bar{\mathcal{E}}_1(h) = e_{xf}(h) - \bar{e}_x = 0 \quad (28)$$

and/or 
$$\bar{\mathcal{E}}_2(h) = e_{yf}(h) - \bar{e}_y = 0 \quad (29)$$

where the subscript f denotes the impact point and the quantities  $\bar{e}_x$  and  $\bar{e}_y$  are the allowable errors in the x and y variables at impact, respectively. Equations (7) and (8) require the number of steps between the n-th and f-th points. Moreover, estimates of the range and/or maximum altitude will be required since the allowable error is specified as a certain percentage of these quantities.

Equations (28) and/or (29) are solved by the method of double false position with a convergence criterion of  $\frac{h_1 - h_2}{h_1} < .05$

where  $\bar{\mathcal{E}}_i(h_1) \geq 0$  and  $\bar{\mathcal{E}}_i(h_2) < 0, i=1,2$ . The starting value of the iteration  $h_0 = .01V/g$  followed by  $3.5 h_0 = h_2$  if  $\bar{\mathcal{E}}_i(h_0) < 0$  or by  $.1 h_0 = h_1$  if  $\bar{\mathcal{E}}(h_0) > 0$ . The maximum step size is .035 V/g which is consistent with assumption 2. Time increments less than .000035V/g are not permitted.

The following formulas are employed to obtain the required estimates:

$$(f-n) = \Delta t / h \quad (30)$$

where 
$$\Delta t = \frac{1}{g} \left[ \dot{y}_m + \sqrt{\dot{y}_m^2 + 2gy_m} \right] + t_m - t_n \quad (31)$$

or 
$$\Delta t = t^* - t_n \quad \text{such that} \quad y(t^*) = 0 \quad (31.1)$$

where  $t_m$  is the starting point for the terminal ballistic phase of the trajectory. The time  $t_m$  will be specified in the thrust table.

The terminal ballistic phase (Phase IV) impact range and maximum altitude are estimated from a linear drag model. They are given by:

$$x_{max} = x_n - \frac{1}{g} \sum_{i=n}^f \frac{\Delta U_i}{\sqrt{1-U_i^2} A(U_i)} \quad (32)$$

$$y = y_n - \frac{1}{g} \sum_{i=n}^f \frac{U_i \Delta U_i}{(1-U_i^2) A(U_i)} \quad (32.1)$$

$$y_{max} = \sup. \{ y \parallel y_i, i = n, \dots, f \} \quad (33)$$

$$U_{i+1} = U_i + \Delta U_i \quad (33.1)$$

$$U_n = \sin \theta_n \quad (33.2)$$

where

$$y_f \leq 0 \quad \text{defines "f"}$$

$$A(U) = \left\{ \sqrt{1-U^2} \left[ \frac{1}{V_n \cos \theta_n} + \frac{\beta}{g} \tan \theta_n \right] - \frac{\beta}{g} U \right\}^2 \quad (33.3)$$

$$\Delta U_i = \begin{cases} (U_n + .9995) / 20 & U > U_{f-1} \\ (U_n + .9995) y_{f-1} / [20(y_{f-1} - y_f)] & \end{cases} \quad (33.4)$$

$$\beta = \rho d^2 V_n K_D \quad (33.5)$$

The following approximation is made for the model trajectory:

$$\rho = \left[ .00234 \text{ lb/ft}^3 \right] \times 10^{-m}$$

where

m=0	0 ft ≤ y < 58,000 ft
m=1	58,000 ft ≤ y < 100,000 ft
m=2	100,000 ft ≤ y < 160,000 ft
m=3	160,000 ft ≤ y < 230,000 ft
m=4	230,000 ft ≤ y < 300,000 ft
m=5	300,000 ft ≤ y < 400,000 ft
m=6	400,000 ft ≤ y < 600,000 ft
m=7	600,000 ft ≤ y

Estimates of the dependent variables for an intermediate ballistic phase (Phase II) from  $t_j$  to  $t_g$  follow:

$$V_g = V_j - (g \sin \theta_j + \rho K_D d^2 V_j^2 / m)(t_j - t_g) \quad (34)$$

$$\bar{V} = 0.5 (V_j + V_g) \quad (34.1)$$

$$\theta_g = \theta_j - g \cos \theta_j (t_g - t_j) / \bar{V} \quad (35)$$

$$\theta_j = 0.5 (\theta_g + \theta_j) \quad (35.1)$$

$$x_g = x_j + 0.8 V_j \cos \theta_j (t_g - t_j) \quad (36)$$

$$y_g = y_j + 0.8 V_j \sin \theta_j (t_g - t_j) \quad (37)$$

The velocity change for a thrust phase from  $t_h$  to  $t_k$  has been calculated from linear drag approximation. Estimates for thrust phases are:

$$\alpha = g \sin \theta_h \quad (38)$$

$$\beta = \rho K_D d^2 V_h \quad (39)$$

$$V_k = \frac{T(t_k)}{\beta} - \frac{m(t_k)}{\beta - \dot{m}} \left[ \frac{\dot{T}}{\beta} + \alpha \right] + \left[ V_h + \frac{m(t_k)}{\beta - \dot{m}} \frac{\dot{T}}{\beta} + \alpha - \frac{T(t_h)}{\beta} \right] \left[ \frac{m(t_k)}{m(t_h)} \right]^{\frac{\beta}{\dot{m}}} \quad (40)$$

where

$$\begin{aligned} T &= T_h + \dot{T}(t-t_h) \\ m &= m_h - \dot{m}(t-t_h) \end{aligned} \quad t_h \leq t \leq t_K \quad (41)$$

$$V_2 = 0.5 (V_h + V_K) \quad (42)$$

$$\theta_K = \theta_h - g \cos \theta_h (t_K - t_h) / V_2 \quad (43)$$

$$\theta_2 = 0.5 (\theta_h + \theta_K) \quad (43.1)$$

$$x_K = x_h + 0.8 V_2 \cos \theta_2 (t_K - t_h) \quad (44)$$

$$y_K = y_h + 0.8 V_2 \sin \theta_2 (t_K - t_h) \quad (45)$$

#### B. Computer Technique

A number of refinements have been incorporated in TEA-2 in order to generate reasonable error estimates. These refinements include:

1. Conservative range estimates.
2. Insuring that the truncation error coefficients do not decrease by a factor of more than .8 from the last time they were computed unless a phase change occurs.
3. Averaging the estimated error at the (n+N)-th step such that it is one-half the sum of estimates based upon local values at the n-th and (n+N)-th steps provided that N steps have been taken since the last step selection and that a phase change does not occur at n+N.
4. The acceptable percentage error is doubled if the criteria cannot be satisfied.



The TEA-2 trajectory program may be utilized to compute two-dimensional, point mass trajectories for one and two stage rockets and/or ballistic projectiles and consists of the following phases:

Phase I	Acceleration of Booster and Main Stage
Phase II	Coasting of Main Stage
Phase III	Acceleration of Main Stage
Phase IV	Free-flight of Main Stage

Any of the above phases may be excluded in the computations; for ballistic trajectory computations, only Phase IV is required.

The following are program conditions:

1. Control systems are not considered
2. A flat earth model is assumed
3. Winds are not considered
4. ARDC Standard Atmosphere, 1959
5. Constant thrust or thrust variable with time
6. Thrust modification for atmospheric pressure changes
7. Constant linear weight change or weight variable with time for rocket boosted phases
8.  $k_D$  or  $C_D$  drag coefficients may be used
9. Form factor to alter drag coefficient

Thrust values for the acceleration phases (I & III) are obtained in the computations by linear interpolation of a thrust (lb) versus time (seconds) table when table values are presented; however, a constant thrust force may be presented instead of tables.

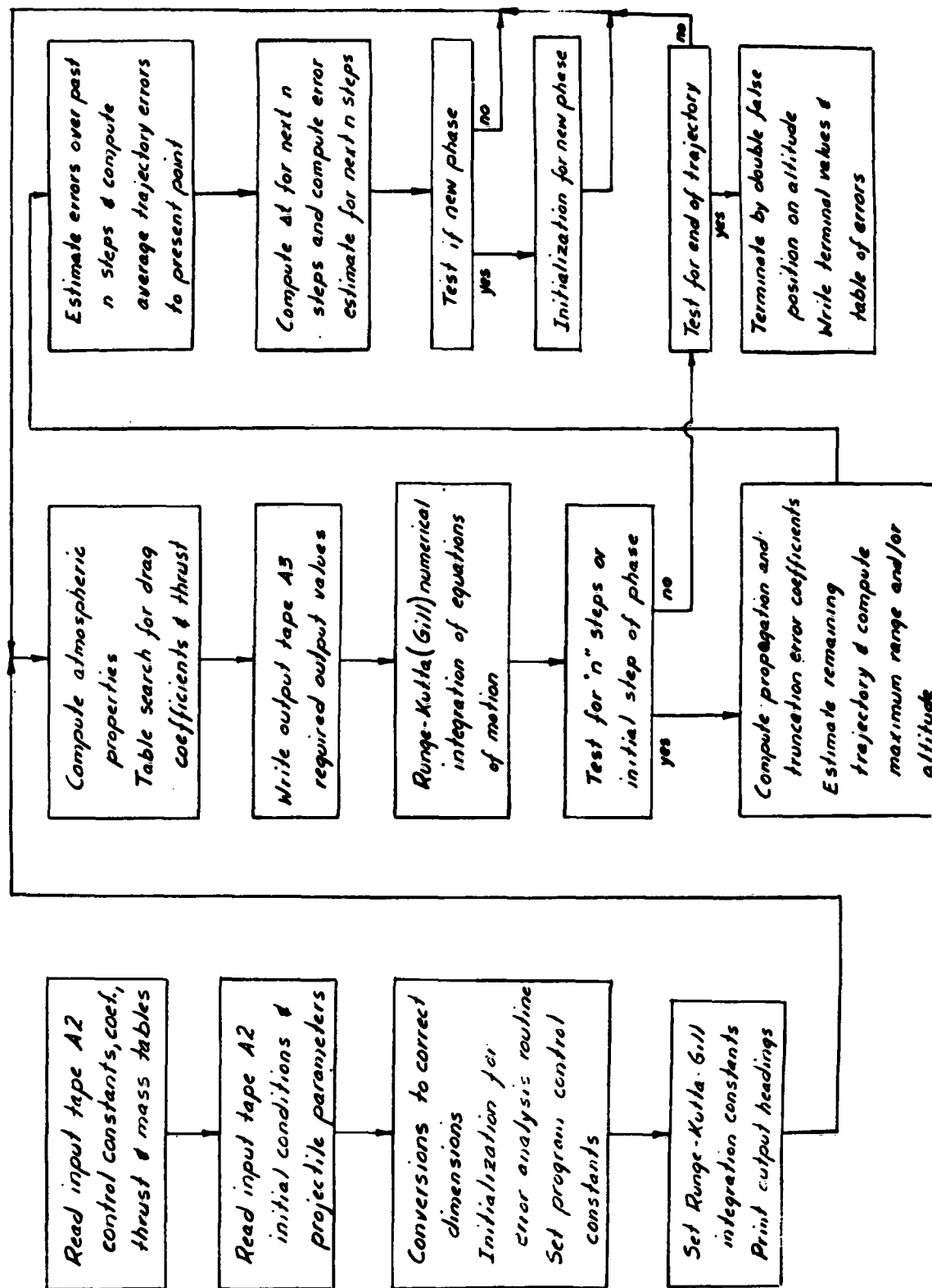
A constant weight change (burning rate, lb/sec) or a table of weight (lb) versus time (seconds) may be introduced into the computations for rocket boosted missiles. Using the table, weight is obtained in the program by linear interpolation. When tables are not presented, the weight is decreased during thrust phases by a factor of integration increment (seconds) multiplied by the burning rate for each step of integration.

Tables of drag coefficients ( $C_D$  or  $k_D$ ) versus mach numbers may be presented for each acceleration phase to be computed and for the free-flight phase. If only Phase IV (i.e., ballistic trajectory) is to be computed, then only the drag coefficient table for free-flight is required.

A constant drag coefficient may be presented for the entire trajectory. (See description for Card #1.)

A generalized and a detailed flow chart are presented in order to depict the program logic. The corresponding FORTRAN listing can be found in Appendix I. Reference should be made to the flow charts prior to any modification due to the complexity of the branching operations in the body of the program. This program requires 7024 words of core storage.

**TRAJECTORY ERROR ANALYSIS for TWO-DEGREE-OF-FREEDOM TRAJECTORIES**  
 Computer Program TEA-2  
 Generalized Flow Chart

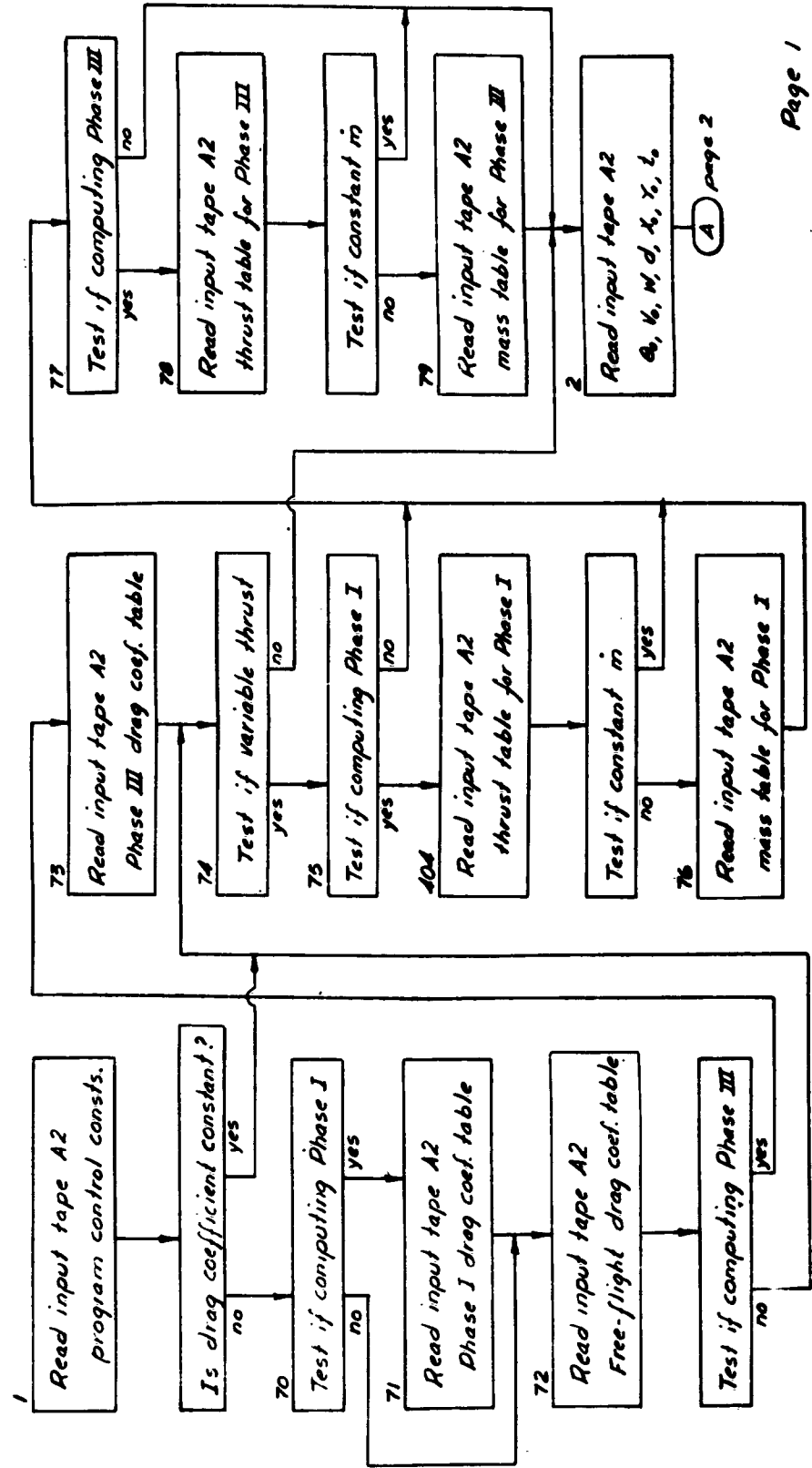


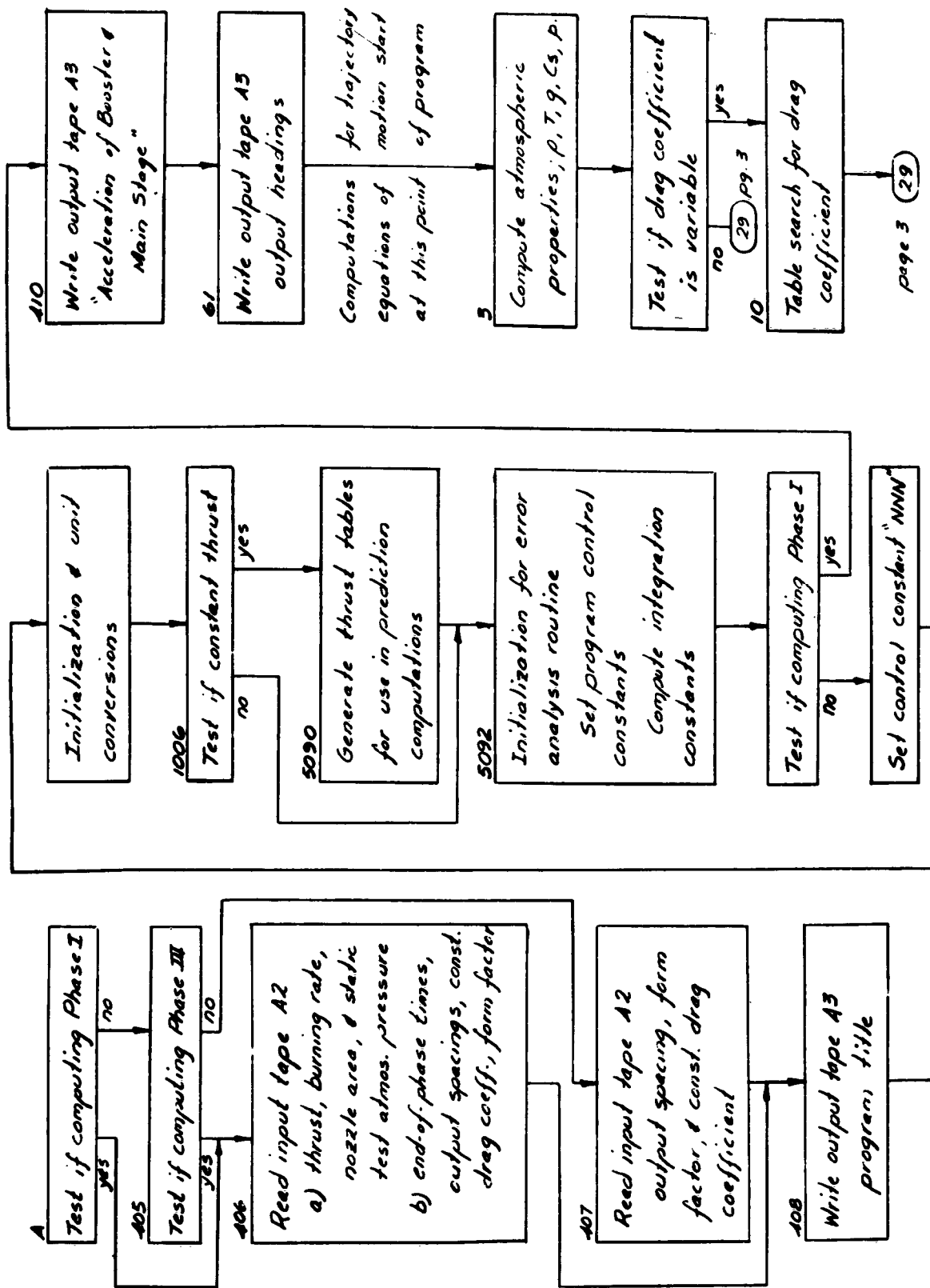
# **TRAJECTORY ERROR ANALYSIS for TWO-DEGREE-OF-FREEDOM TRAJECTORIES** Computer Program TEA-2

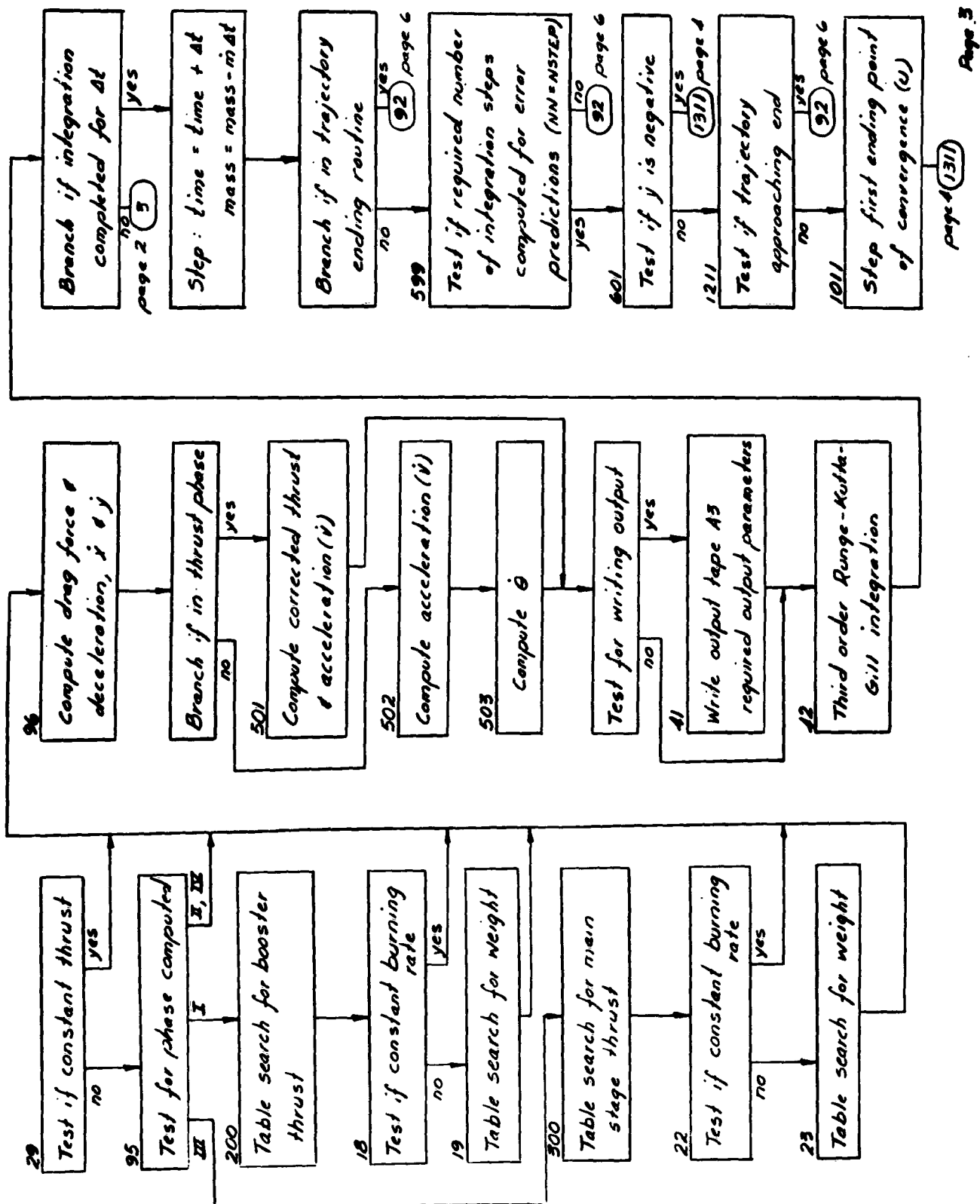
ANALYSIS : Dr. H. J. Kopp  
PROGRAMMING : Mr. J. N. Nielsen

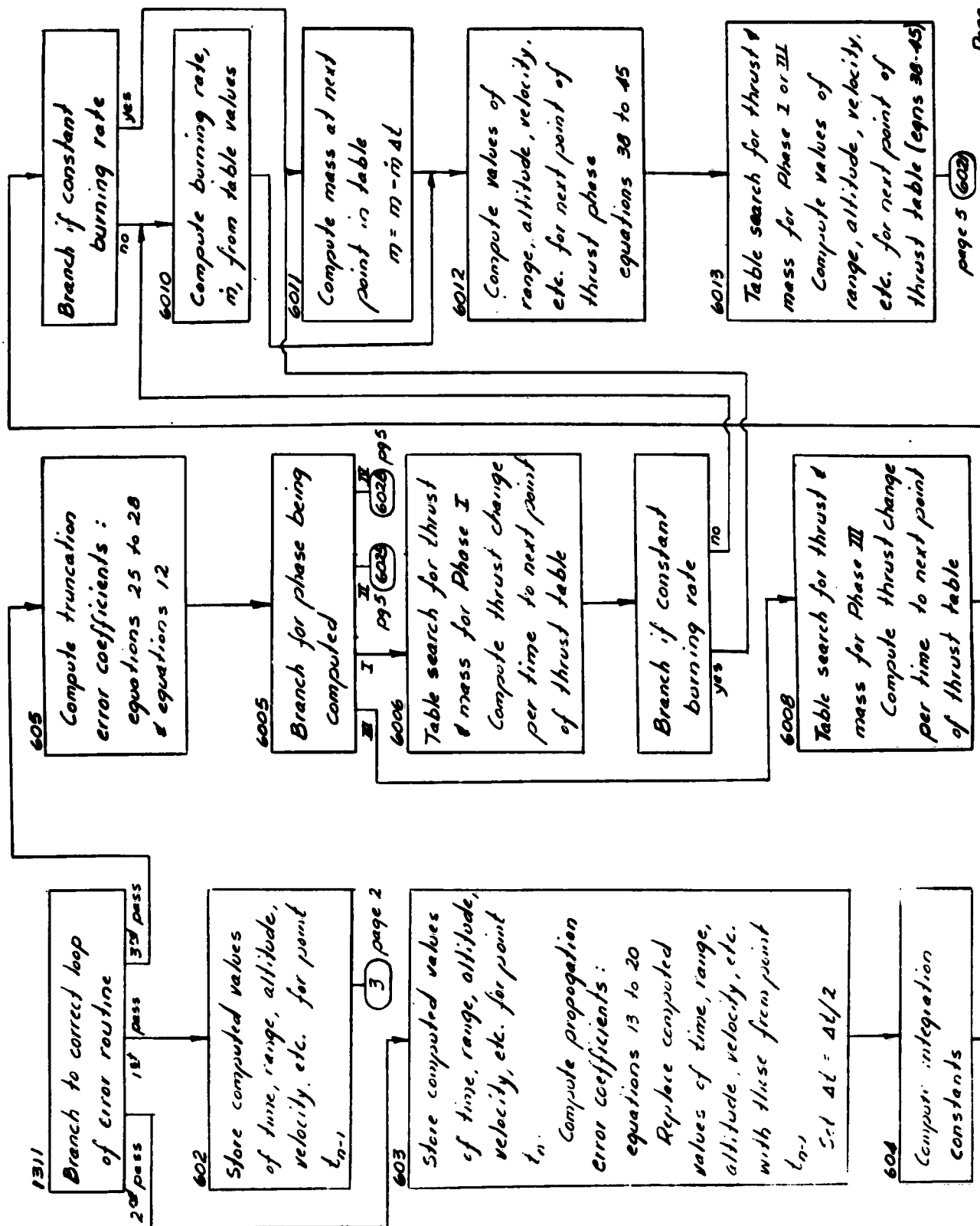
ORGANIZATION: Computing & Analysis Section  
Engineering Sciences Lab.  
Picatinny Arsenal

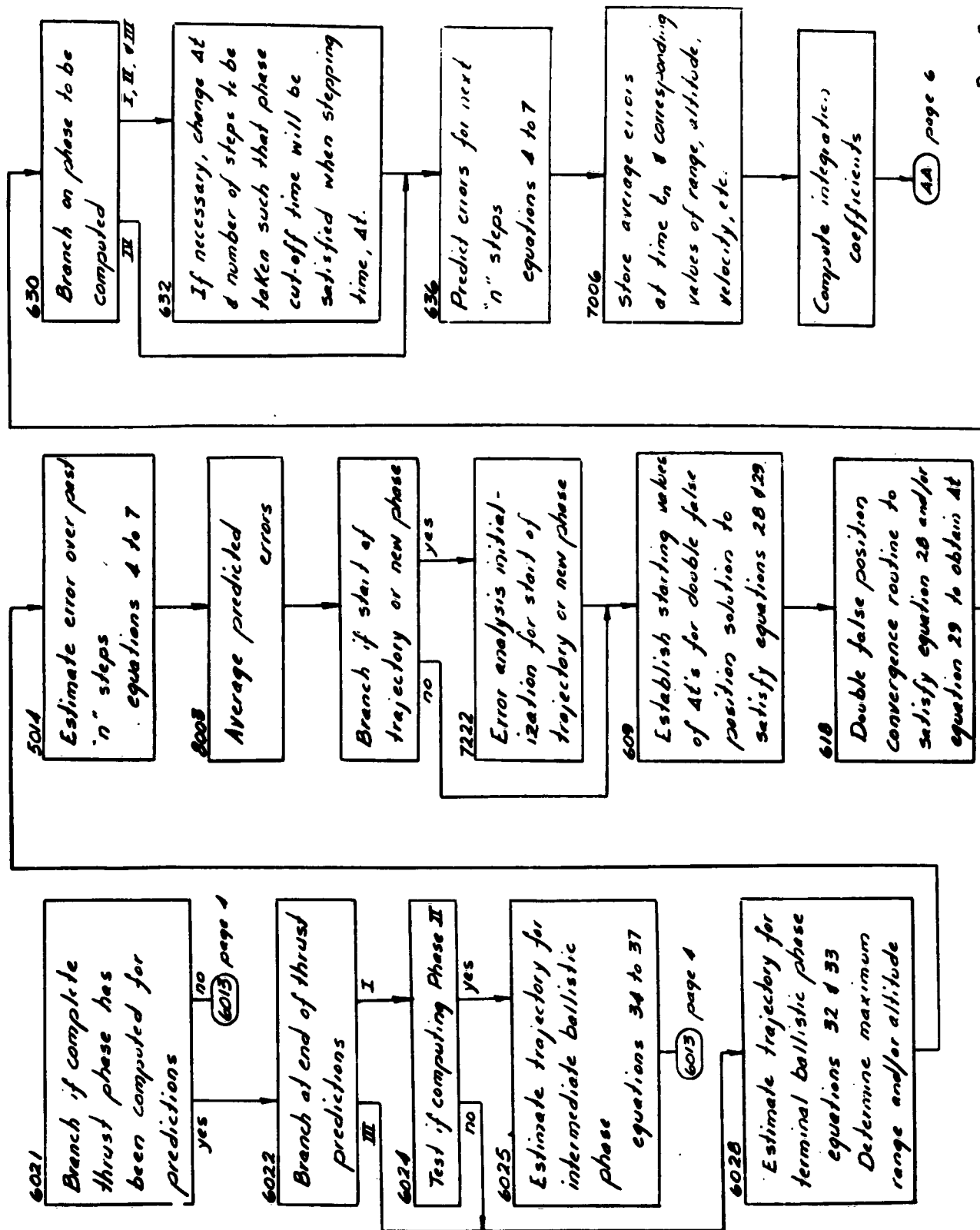
## Detailed Flow Chart















### C. Computer Usage

The procedures for preparing input data to trajectory program TEA-2 are discussed in this section, and examples of typical cases are presented and described.

Input data is punched on cards which are loaded with the program deck onto tape. Data sheets which may be used for presenting required data for key-punching are illustrated in the descriptions of sample trajectory cases to be computed. The computer program reads input data from Tape A2 which is the standard for IBM FORTRAN Monitor Systems.

Descriptions of input requirements will consist of two parts:  
(1) Rocket trajectories and, (2) Ballistic trajectories.

## 1. Rocket Trajectory Input

Card #1 contains nine one-digit and three two-digit control parameters from columns 1 through 15. Columns 16 to 20 are for a decimal input number. These parameters are to be presented across card #1 as follows:

Card #1 .... NEXT(1), NEXT(2), NEXT(3), NEXT(4), KDCON,  
NTHRST, KD, M, NXY, JN, NJR, NS, GAMMA  
Format (9I1, 3I2, F5.0)

where:

NEXT(1) .... equal to 0 for not computing Phase I  
equal to 1 for computing Phase I

NEXT(2) .... equal to 0 for not computing Phase II  
equal to 1 for computing Phase II

NEXT(3) .... equal to 0 for not computing Phase III  
equal to 1 for computing Phase III

NEXT(4) .... equal to 0 for not computing Phase IV  
equal to 1 for computing Phase IV

KDCON .... equal to 1 for variable drag coefficients  
(use tables)  
equal to 2 for constant drag coefficient

NTHRST .... equal to 1 for using thrust tables  
equal to 2 for not using thrust tables

KD ..... equal to 1 for using  $k_D$  coefficients  
equal to 2 for using  $C_D$  coefficients

M ..... equal to 1 for using weight table  
equal to 2 for not using weight table

NXY ..... equal to 1 for step selection based on range  
                     error criterion  
                     equal to 2 for step selection based on  
                     maximum altitude  
                     equal to 3 for step selection based on total  
                     range and maximum altitude  
  
 JN ..... number of trajectories to be computed for the  
                     same conditions of error limit, thrust and  
                     drag coefficients (a two digit integer)  
  
 NJR ..... trajectory identification number for first  
                     trajectory to be computed ( a two digit integer)  
  
 NS ..... number of integration steps to be computed  
                     for error estimations (a two digit integer; if  
                     left blank on card, set equal to ten in program)  
  
 GAMMA ... percent error limit for trajectory computations  
                     (if left blank on input card, GAMMA is set equal  
                     to 5.0% in program)

Cards #2 to #7 contain the drag coefficient table for Phase I. Cards  
 #2 to #4 consist of the table mach numbers, and cards #5 to #7 contain  
 the corresponding drag coefficients.

Cards #8 to #13 contain drag coefficient tables for free-flight phases  
 (Phases II and IV). Cards #8 to #10 are for the table mach numbers, and  
 cards #11 to #13 are for the corresponding drag coefficients.

Cards #14 to #19 contain the drag coefficient for Phase III. Cards  
 #14 to #16 are for the table mach numbers, and cards #17 to #19 are for  
 the corresponding drag coefficients.

Either  $k_D$  or  $C_D$  coefficients may be used in the tables; however,  
 values that are to be used must be specified by the control parameter  
 KD in card #1. All of the coefficient tables may be eliminated as input  
 when in card #1 KDCON = 2.

Cards #20 to #25 contain the thrust table for Phase I. This table is not required when a constant thrust force is to be used; and for this case, the control parameter NTHRST in card #1 must equal 2, and a thrust value must be presented in card #46. Cards #20 to #22 are for the table time values, and cards #23 to #25 are for the corresponding table thrust values.

Cards #26 to #31 contain the weight table for Phase I and must be presented only if in card #1  $M=1$ . Cards #26 to #28 are for table time values, and cards #29 to #31 are the corresponding table values of weight.

Cards #32 to #37 contain the thrust table for Phase III. These cards are not required when a constant thrust value is to be used; and for this case, NTHRST must equal 2 in card #1 and a constant thrust value must be presented in card #46. Cards #32 to #34 are for table time values, and cards #35 to #37 are for the corresponding table thrust values.

Cards #38 to #43 contain the weight table for Phase III and must be presented when constant burning rates are not used (in card #1  $M=1$ ). Cards #38 to #40 are for table time values, and cards #41 to #43 are the corresponding table values of weight.

Data field widths for all input values are nine columns, and eight values may be introduced on one card. Tables are required only for phases that are to be computed. Each table that is required by the program will consist of six input cards; therefore, if data is not available for completing the maximum table requirements, blank cards must be used to supply the proper number of cards.

The last three cards required for input (cards #44, 45, and 46) will be listed along with input symbols, and these cards are required for each rocket trajectory to be computed. Using the same error criteria, thrust, weight, and drag coefficient tables, "JN" trajectories may be computed by varying initial conditions, configuration, etc., in cards #44, 45 and 46.

Card #44.....THDEGO, VO, WGT, DIA, XO, YO, TO, YF

where:

THDEGO ... initial quadrant elevation, degrees  
VO ..... initial velocity, feet per second  
WGT ..... total weight, pounds  
DIA ..... missile diameter, inches  
XO ..... initial range, feet  
YO ..... initial altitude, feet  
TO ..... time at start of trajectory, seconds  
YF ..... terminal altitude, feet

Card #45..... THRST, DOTM, AREA, BWGT, THR2, DOTM2,  
AREA2, PRESO

WHERE:

THRST ..... booster thrust, pounds  
DOTM ..... booster burning rate, lb per second  
AREA ..... nozzle throat area of booster, sq. in.  
BWGT ..... booster weight (w. o. propellant), pounds  
THR2 ..... main stage thrust, pounds  
DOTM2 ..... main stage burning rate, lb per second  
AREA2 ..... nozzle throat area of main stage, sq. in.  
PRESO ..... static test atmospheric pressure

AREA, AREA2 and PRESO are to be presented for input only when the thrust is to be modified in the computations for atmospheric pressure changes. For this correction not to be performed, AREA and AREA2 must be made equal to zero or left blank on the input card.

Card #46 ..... TIM(1), TIM(2), TIM(3), DWRT(1), DWRT(2),  
DWRT(4), CKD, FACT

where:

TIM(1) ..... end of Phase I, seconds  
TIM(2) ..... end of Phase II, seconds  
TIM(3) ..... end of Phase III, seconds  
DWRT(1) ..... output spacing for Phases I and III, seconds  
DWRT(2) ..... output spacing for Phase II, seconds  
DWRT(4) ..... output spacing for Phase IV, seconds  
CKD ..... constant drag coefficient  
FACT ..... form factor (if left blank on input card,  
form factor is set equal to one)

ALL DATA PRESENTED ON CARDS #2 TO #46 MUST HAVE  
DECIMAL POINTS AND HAVE FIELD WIDTHS OF NINE COLUMNS.

#### Rocket Trajectory Sample Input Case

The rocket sample case is for a one stage rocket which would  
require computing Phases I and IV of the program.

The following conditions represent the trajectory input requirements:

1.  $C_D$  drag coefficient tables
2. constant burning rate (5 lbs/sec)
3. constant thrust (100 lbs)
4. step selection based on range error criteria
5. 10 integration steps per estimate
6. quadrant elevation =  $45.0^\circ$
7. initial velocity = 1000.0 fps
8. weight = 100.0 lbs
9. diameter = 11.0 inches
10. burning time = 4.0 seconds
11. output spacing every  $\Delta t$
12. form factor = 1.0
13. 5.0% error limit

For the above conditions, the following data must be presented in card #1:

NEXT(1)	= 1, compute Phase I
NEXT(2)	= 0, do not compute Phase II
NEXT(3)	= 0, do not compute Phase III
NEXT(4)	= 1, compute Phase IV
KDCON	= 1, variable drag coefficients presented
NTHRST	= 2, constant thrust
KD	= 2, using $C_D$ drag coefficients
M	= 2, not presenting weight tables (constant burning rate)
NXY	= 1, step selection based on range error criteria
JN	= 01, compute one trajectory
NJR	= 01, trajectory numbered 1
NS (blank)	, ten integration steps per estimate
GAMMA (blank)	, 5.0% acceptable error

An illustration of the presentation of data on card #1 may be seen on page 33.

The drag coefficient tables for Phase I and Phase IV as presented for key-punching are shown on the table data sheet on page 32. These tables are punched onto cards #2 to #13, and the punched cards are illustrated on page 33.

Cards #14 to #19 are not required for input as Phase III is not to be computed.

Cards #20 to #43 are not required for input as thrust and weight tables are not to be presented.

The following data must be punched on card #44:

THDEGO (45.0),	quadrant elevation, degrees
VO (1000.0),	initial velocity, fps
WGT (100.0),	missile weight, lbs
DIA (11.0),	missile diameter, inches

Values for XO, YO, TO, and YF do not have to be punched on the card for this case as they equal zero.



The following data must be punched on card #45:

THRST (100.0), constant thrust force, lbs  
DOTM (5.0), burning rate, lbs/sec

Values for AREA, BWGT, THR2, DOTM2, AREA2, and PRESO do not have to be punched on the card as this data is not required for the given rocket.

In card #46, only the following need be punched:

TIM(1) (4.0), end of Phase I, seconds

TIM(2) and TIM(3) are not required as Phases II and III are not being computed.

DWRT(1), DWRT(2), and DWRT(4) are left blank as output is to be printed for every integration increment,  $\Delta t$ .

CKD is left blank as table values of drag coefficients are presented.

FACT is left blank as a form factor equal to 1.0 is required; however, a value of 1.0 may be punched for FACT.

Data presented for key-punching onto cards #44, #45 and #46 may be seen on the input sheet on page 31. An illustration of this data on cards may be seen on page 33.

## INPUT FOR TRAJECTORY PROGRAM TEA-2

### For Ballistic and Rocket Trajectory

QUADRANT ELEVATION, degrees  
INITIAL VELOCITY, ft/sec  
TOTAL WEIGHT, lbs  
DIAMETER, inches  
INITIAL RANGE, ft  
INITIAL ALTITUDE, ft  
INITIAL TIME, sec  
TERMINAL ALTITUDE, ft

45.  
1000.  
100.  
11.0  
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### For Rocket Trajectory

BOOSTER THRUST, lbs  
BOOSTER BURNING RATE, lb/sec  
BOOSTER NOZZLE AREA, sq. inches  
BOOSTER WEIGHT (EMPTY), lbs  
MAIN STAGE THRUST, lbs  
MAIN STAGE BURNING RATE, lbs/sec  
MAIN STAGE NOZZLE AREA, sq. inches  
STATIC TEST ATMOS. PRESSURE, lb sec<sup>2</sup>ft<sup>-4</sup>

100.  
5.0  
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### For Rocket Trajectory

TIME AT END OF PHASE I, sec  
TIME AT END OF PHASE II, sec  
TIME AT END OF PHASE III, sec  
OUTPUT SPACING FOR PHASES I & III, sec  
OUTPUT SPACING FOR PHASE II, sec  
OUTPUT SPACING FOR PHASE IV, sec  
CONSTANT DRAG COEFFICIENT  
FORM FACTOR

4.0  
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### For Ballistic Trajectory

OUTPUT SPACING, sec  
FORM FACTOR  
CONSTANT DRAG COEFFICIENT

~~\_\_\_\_\_~~  
~~\_\_\_\_\_~~  
~~\_\_\_\_\_~~

# Table Data Sheet for TEA-2 Trajectory Program

Name \_\_\_\_\_

Date \_\_\_\_\_

Argument mach no.	0.0	0.6	0.8	0.9	1.0	1.1	1.2	1.3
	1.4	1.5	1.6	1.8	2.0	2.5	3.0	4.0
	5.0							
Function $C_D$ (Phase I)	.13	.13	.14	.175	.255	.277	.284	.275
	.26	.241	.228	.204	.186	.161	.153	.141
	.132							

Argument mach no.	0.0	0.6	0.8	0.9	1.0	1.1	1.2	1.3
	1.4	1.5	1.6	1.8	2.0	2.5	3.0	4.0
	5.0							
Function $C_D$ (Phase IV)	.13	.13	.14	.175	.255	.277	.284	.275
	.26	.241	.228	.204	.186	.161	.153	.141
	.132							

Argument								
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## 2. Ballistic Trajectory Input

Card #1 contains the same values as in card #1 described for rocket trajectories on page 24.

Card #2 to #7 contain the drag coefficient table. Card #2 to #4 are for the table mach numbers, and cards #5 to #7 are for the corresponding drag coefficients. This table is not required when  $KDCON = 2$  in card #1. For this case, the constant drag coefficient must be presented in card #9.

Either  $k_D$  or  $C_D$  drag coefficients may be used, and values employed must be specified by the control parameter KD in card #1.

Card #8 ..... THDEGO, VO, WGT, DIA, XO, YO, TO, YF

where:

THDEGO ..... initial quadrant elevation, degrees  
VO ..... initial velocity, feet per second  
WGT ..... total weight, pounds  
DIA ..... missile diameter, inches  
XO ..... initial range, feet  
YO ..... initial altitude, feet  
TO ..... time at start of trajectory, seconds  
YF ..... terminal altitude, feet

Card #9 ..... DWRT(4), FACT, CKD

where:

DWRT(4) ..... output spacing, seconds  
FACT ..... form factor  
CKD ..... constant drag coefficient

ALL DATA PRESENTED ON CARDS #2 TO #9 MUST HAVE  
DECIMAL POINTS AND HAVE FIELD WIDTHS OF NINE COLUMNS.

### Ballistic Trajectory Sample Input Case

The following conditions are for the sample ballistic trajectory:

1.  $C_D$  drag coefficient table
2. initial velocity = 1000. fps
3. quadrant elevation =  $45.0^\circ$
4. weight = 100.0 lbs
5. diameter = 11.0 inches
6. output spacing every  $\Delta t$
7. form factor = 1.0
8. ten integration steps per estimate
9. 0.5% error limit

For the above conditions, the following data must be presented in card #1:

NEXT(1)	= 0, do not compute Phase I
NEXT(2)	= 0, do not compute Phase II
NEXT(3)	= 0, do not compute Phase III
NEXT(4)	= 1, compute Phase IV
KDCON	= 1, variable drag coefficients presented
NTHRST	= 2, no thrust
KD	= 2, using $C_D$ drag coefficients
M	= 2, not presenting weight tables
NXY	= 2, step selection based on altitude error criteria
JN	= 01, compute one trajectory
NJR	= 01, trajectory numbered 1
NS	= 10, integration steps per estimate
GAMMA	= 0.5, percent acceptable error

An illustration of the presentation of data on card #1 may be seen on page 37.

The drag coefficient table for the ballistic trajectory as presented for key-punching is shown on the table data sheet on page 38. This table is punched onto cards #2 to #7, and the punched cards are illustrated on page 39.

The following data must be punched on card #8:

THDEGO (45.0), quadrant elevation, degrees  
VO (1000.0), initial velocity, fps  
WGT (100.0), missile weight, lbs  
DIA (11.0), missile diameter, inches

Values of XO, YO, TO, and YF do not have to be punched on the card for this case as they equal zero.

Card #9 may be left blank. No value is required for CKD as a table of drag coefficients is to be presented. No value is required for DWRT(4) as output is required every integration step,  $\Delta t$ . No value is required for FACT as the form factor must equal one.

Data presented for key-punching onto cards #8 and #9 may be seen on the input sheet on page 37 . An illustration of this data on cards may be seen on page 38 .

## INPUT FOR TRAJECTORY PROGRAM TEA-2

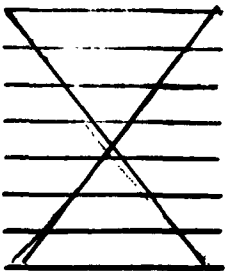
### For Ballistic and Rocket Trajectory

QUADRANT ELEVATION, degrees  
INITIAL VELOCITY, ft/sec  
TOTAL WEIGHT, lbs  
DIAMETER, inches  
INITIAL RANGE, ft  
INITIAL ALTITUDE, ft  
INITIAL TIME, sec  
TERMINAL ALTITUDE, ft

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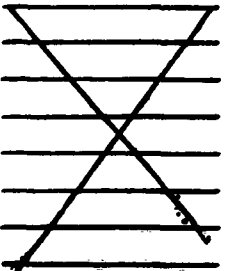
### For Rocket Trajectory

BOOSTER THRUST, lbs  
BOOSTER BURNING RATE, lb/sec  
BOOSTER NOZZLE AREA, sq. inches  
BOOSTER WEIGHT (EMPTY), lbs  
MAIN STAGE THRUST, lbs  
MAIN STAGE BURNING RATE, lbs/sec  
MAIN STAGE NOZZLE AREA, sq. inches  
STATIC TEST ATMOS. PRESSURE, lb sec<sup>2</sup>ft<sup>-4</sup>



### For Rocket Trajectory

TIME AT END OF PHASE I, sec  
TIME AT END OF PHASE II, sec  
TIME AT END OF PHASE III, sec  
OUTPUT SPACING FOR PHASES I & III, sec  
OUTPUT SPACING FOR PHASE II, sec  
OUTPUT SPACING FOR PHASE IV, sec  
CONSTANT DRAG COEFFICIENT  
FORM FACTOR



### For Ballistic Trajectory

OUTPUT SPACING, sec  
FORM FACTOR  
CONSTANT DRAG COEFFICIENT

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# Table Data Sheet for TEA-2 Trajectory Program

Name \_\_\_\_\_

Date \_\_\_\_\_

Argument mach no.	0.0	0.6	0.8	0.9	1.0	1.1	1.2	1.3
	1.4	1.5	1.6	1.8	2.0	2.5	3.0	4.0
	5.0	7.0	9.0	11.0	15.0	30.		
Function C <sub>0</sub>	.13	.13	.14	.175	.255	.277	.284	.275
	.26	.241	.228	.204	.186	.161	.153	.141
	.132	.122	.112	.102	.10	.10		

Argument								
Function								

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## BALLISTIC TRAJECTORY INPUT

00011222201010 0.5										CARD 1																																																																															
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80										
1.4										1.5										1.6										1.8										2.0										2.5										3.0										4.0										CARD 3									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80										
3.0										7.0										9.0										11.0										15.0										30.0										CARD 4																													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80										
.13										.13										.14										.175										.255										.277										.284										.275										CARD 5									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80										
.26										.241										.228										.204										.186										.161										.153										.141										CARD 6									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80										
.132										.																																																																															

GENERAL PURPOSE 8 FIELD

## RESULTS AND DISCUSSION

The TEA-2 digital computer program for the IBM 709 has been tested on a substantial number of trajectories. This program has always selected reasonable time steps. Time steps for TEA-2 are dependent upon the accuracy specified by the user as well as the problem characteristics. That is, problem initial conditions, body drag characteristics, and vehicle thrust characteristics are important parameters and exert a significant influence on the time increments used by TEA-2.

Analysis of output for typical ballistic flights has shown that the estimated range error is somewhat more than 10 times too conservative. That is, an estimated range error of 1% by TEA-2 would correspond to an actual range error less than 0.1%.

Four typical trajectories were computed in order to establish timing estimates. The program limitation to a maximum angular change per time step of two degrees places an upper limit on computational speed. This limitation explains the small difference in computation time between the 5% and the 0.5% ballistic trajectories presented in Table 1.

The first ballistic trajectory corresponds to the sample input, and sample output presented in Section C and Appendix II, respectively. A similar trajectory and the time steps required for less than 0.5% range error are presented in Figure 2. Actual range error is probably much less than 0.5% in this case. Figure 2 illustrates that maximum time steps were taken from 10.483 seconds to 33.837 seconds.

Figure 3 illustrates a typical rocket trajectory which is similar to the ballistic case. Initial step size is much smaller in this case. The average step size is 25% less than for the ballistic case.

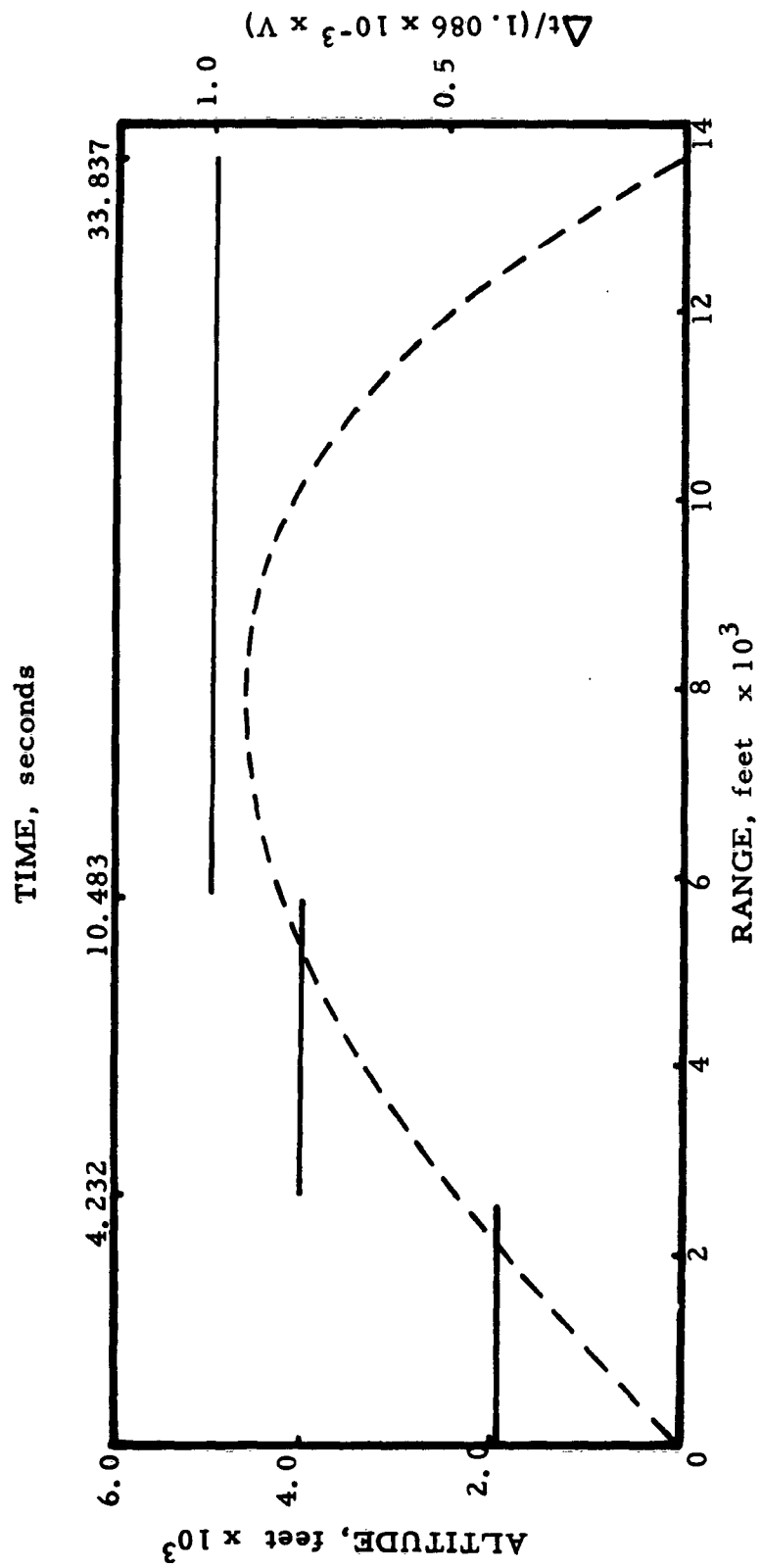
Table 1 lists two typical ballistic trajectories and two typical rocket trajectories. Both 5% and 0.5% range accuracies were requested for these trajectories. These problems were run both on TEA-2 and on the "standard" two-degree of freedom program which utilizes a fixed time increment which is an input quantity. This input time increment is based on the user's experience. The values reported in the table are typical of those presently used. Under the assumption that the four cases presented with flight history constitute the "average" problems, the use of TEA-2 constitutes a time savings of 2.1 and 1.7 for the 5% and 0.5% accuracy specifications, respectively. This will result in a cost reduction of 35,900 dollars per year or 28,500 dollars per year for the respective required accuracies. Cost savings are based on current usage of 19 hours per month at a cost of 300 dollars per hour. The 5% requested accuracy should be the most widely used case.

Computation time is approximately 2.5 to 3.5 times faster than the "standard" program for the usual ballistic and rocket trajectories. However, TEA-2 speed is restricted by output time which results in the computation times reflected in Table 1. Computation times including terminal output and error table output only are also included in Table 1. Clearly, detailed flight history should be printed out only when absolutely necessary.

Very high drag bodies such as parachutes cannot be treated by this program.

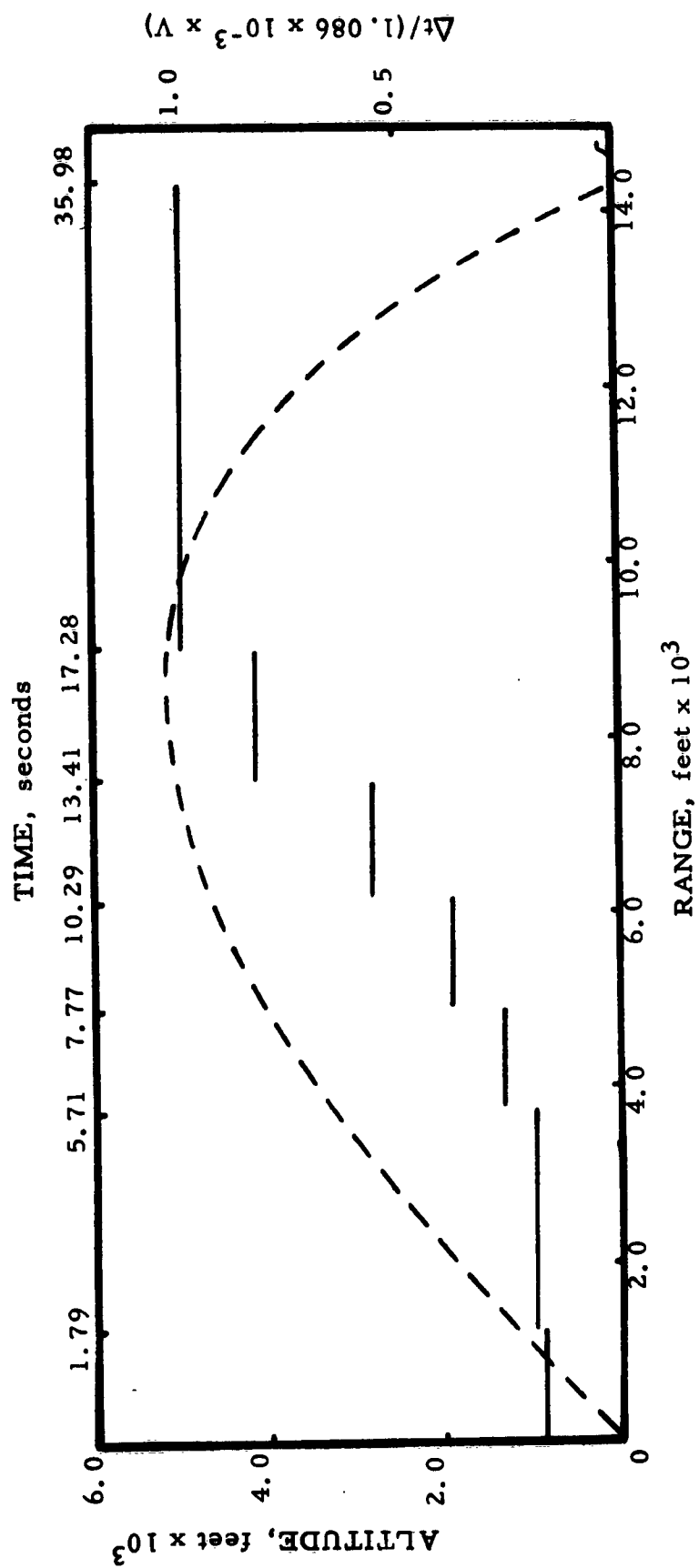
Type of Flight	COMPUTATION TIME (Seconds)				
	Flight History Output TEA-2 5%	TEA-2 0.5%	Terminal Output Only TEA-2 5%	TEA-2 0.5%	Standard Program (RKTCN)
Ballistic Trajectory 1	12.0	13.8	9.6	10.2	29.4
Ballistic Trajectory 2	16.8	19.2	12.6	15.0	36.0
Rocket Trajectory 1	15.6	22.2	10.8	16.2	33.0
Rocket Trajectory 2	21.0	28.8	15.6	21.0	39.6

TABLE 1  
Comparison of Computation Time



BALLISTIC TRAJECTORY  
 LESS THAN 0.5% RANGE ERROR REQUESTED  
 AVERAGE TIME INCREMENT = 0.44 SECONDS

Figure 2



ROCKET TRAJECTORY  
 LESS THAN 0.5% RANGE ERROR REQUESTED  
 AVERAGE TIME INCREMENT = 0.33 SECONDS

Figure 3

APPENDIX I  
FØRTRAN LISTING

THE TEA-2 SOURCE PRØGRAM IS WRITTEN IN FØRTRAN LANGUAGE. IT REQUIRES SINE, CØSINE, SQUARE RØØT, AND EXPØNENTIAL LIBRARY SUBRØUTINES. ALSØ REQUIRED ARE THE ATMØSPHERE (ATMØS) AND TABLE SEARCH (TABLE) SUB-PRØGRAMS WHICH ARE LISTED AFTER THE MAIN PRØGRAM. A FØRTRAN LISTING ØF THE MAIN PRØGRAM FØLLØWS.

```

C TEA-2      TWO-DIMENSIONAL, TWO-STAGE RØCKET ØR BALLISTIC TRAJECTØRY
C              (WITH 1959 ARDC STANDARD ATMØSPHERE)
C              COMPUTING AND ANALYSIS SECTION
C
C      TRAJECTØRY ERROR ANALYSIS ** TWO DEGREES ØF FREEDØM
C      ANALYSIS ** LT. H.J. KØPP, PH.D * EXTENSION 72264
C      PRØGRAMMING ** MR. J.N. NIELSEN * EXTENSION 73230
C
C      THIS PRØGRAM SELECTS THE INTEGRATION STEP LENGTH SUCH THAT THE
C      ERRØR IN THE TØTAL RANGE IS LESS THAN A PRESCRIBED AMØUNT AND/OR
C      THE ERRØR IN ALTITUDE IS LESS THAN A PRESCRIBED AMØUNT.
C
C      DIMENSION  TABL1(24,2),TABL2(24,2),TABL3(24,2),TRST1(24,2),
1      TRST2(24,2),TMAS(24,2),TMAS2(24,2),NEXT(5),TIM(3),
2      DWRT(4),XDØT(3),YDØT(3),VDØT(3),THDØT(3)
C      DIMENSION  TN(200),XN(200),YN(200),THN(200),VN(200),EX(200),
1      EY(200),ET(200),EV(200)
C      COMMON RHO,PRSB,GRAV,CMACH,KDCØN,NATMØS
C
C
C              FØRMAT STATEMENTS
C
100 FØRMAT (9I1,3I2,F5.0)
101 FØRMAT (8F9.0)
104 FØRMAT (7F10.0)
105 FØRMAT (8F5.0)
106 FØRMAT (1H1,43X,31H COMPUTING AND ANALYSIS SECTION/27X,66H TWO DIM
      IENSIONAL, TWO-STAGE RØCKET ØR BALLISTIC TRAJECTØRY PRØGRAM/41X,37H
2      *WITH 1959 ARDC STANDARD ATMØSPHERE=//)
108 FØRMAT (8H1  TIME,7X,6H RANGE,6X,9H ALTITUDE,4X,9H VELØCITY,4X,
1      6H THETA,5X,5H MACH,5X,3H KD,7X,7H THRUST,6X,7H WEIGHT,5X,
2      8H DENSITY)
109 FØRMAT (8H1  TIME,7X,6H RANGE,6X,9H ALTITUDE,4X,9H VELØCITY,4X,
1      6H THETA,5X,5H MACH,5X,3H KD,7X,7H THRUST,6X,7H WEIGHT,5X,
2      8H DENSITY)
110 FØRMAT (14X,8H X-DERIV,5X,8H Y-DERIV,5X,8H V-DERIV,3X,9H TH-DERIV,
1      38X,5H DRAG,6X,9H PRESSURE//)
111 FØRMAT (F9.3,2F14.3,F12.3,F11.3,F1C.4,F9.4,F14.3,F11.3,E15.5)
112 FØRMAT (9X,2F14.3,F12.3,F11.3,33X,F11.3,E15.5)
113 FØRMAT (46X,20H END ØF TRAJECTØRY,I3)
115 FØRMAT (1H1,46X,26H CØASTING ØF MAIN STAGE)
114 FØRMAT (38X,44H ACCELERATION ØF BØØSTER AND MAIN STAGE)
116 FØRMAT (1H1,44X,30H ACCELERATION ØF MAIN STAGE)
117 FØRMAT (1H1,45X,29H FREE-FLIGHT ØF MAIN STAGE)
118 FØRMAT (1H1,36X,59H ACCELERATION ØF BØØSTER AND MAIN STAGE Ø
      1FF LAUNCHER)
121 FØRMAT (47X,26H CØASTING ØF MAIN STAGE)
122 FØRMAT (45X,30H ACCELERATION ØF MAIN STAGE)
123 FØRMAT (46X,29H FREE-FLIGHT ØF MAIN STAGE)

```



```

126 FORMAT (1H1,56X,6H TEA-2/34X,52H TRAJECTORY ERROR ANALYSIS ** TWO
1DEGREES OF FREEDOM//)
127 FORMAT (5X,71H ANALYSIS ** DR. H.J. KOPP * EXTENSION 72264 * REP
10RT TO BE PUBLISHED/5X,50H PROGRAMMING ** MR. J.N. NIELSEN * EXTEN
2SION 73230//)
128 FORMAT (8X,103H THIS PROGRAM SELECTS THE INTEGRATION STEP LENGTH S
UCH THAT THE ERROR IN THE TOTAL RANGE IS LESS THAN A/5X,111H PRESC
RIBED AMOUNT AND/OR THE ERROR IN ALTITUDE IS LESS THAN A PRESCRIBE
3D AMOUNT. THE ERROR CRITERION USED FOR/5X,23H THIS TRAJECTORY WAS
4 **)
129 FORMAT (8X,85H THE ABOVE CONDITION WAS SATISFIED, AND THE COMPUTED
1 ERROR IN TOTAL RANGE IS EQUAL TO,E15.8,9H PERCENT.//)
130 FORMAT (8X,93H THE ABOVE CONDITION COULD NOT BE SATISFIED, AS THE
1COMPUTED ERROR IN TOTAL RANGE IS EQUAL TO/6X,E15.8,9H PERCENT.//)
131 FORMAT (28X,39H THE ERROR IN TOTAL RANGE IS LESS THAN ,F6.2,
1
9H PERCENT.//)
132 FORMAT (28X,45H THE ERROR IN TERMINAL ALTITUDE IS LESS THAN ,F6.2,
1
29H PERCENT OF MAXIMUM ALTITUDE.//)
133 FORMAT (50X,22H FINAL ERROR ESTIMATES/57X,6H *****)
134 FORMAT (5X,7H RANGE ,E15.8,14H RANGE ERROR ,E15.8,11H ALTITUDE ,
1
E15.8,17H ALTITUDE ERROR ,E15.8/5X,7H THETA ,E15.8,
2
14H THETA ERROR ,E15.8,11H VELOCITY ,E15.8,
3
17H VELOCITY ERROR ,E15.8//)
135 FORMAT (51X,19H INITIAL CONDITIONS/57X,6H *****)
136 FORMAT (8X,7H RANGE ,E15.8,3X,10H ALTITUDE ,E15.8,3X,7H THETA ,
1
E15.8,3X,10H VELOCITY ,E15.8//)
137 FORMAT (47X,25H TABLE OF ERROR ESTIMATES/56X,6H *****)
138 FORMAT (1H1,40X,37H TABLE OF ERROR ESTIMATES (CONTINUED)/56X,
1
6H *****)
139 FORMAT (11X,5H TIME,17X,6H RANGE,16X,9H ALTITUDE,15X,6H THETA,16X,
1
9H VELOCITY/30X,12H RANGE ERROR,10X,15H ALTITUDE ERROR,9X,
2
12H THETA ERROR,10X,15H VELOCITY ERROR//)
140 FORMAT (6X,E15.8,4(8X,E15.8)/21X,4(8X,E15.8)//)
141 FORMAT (5X,24H IMPACT BETWEEN RANGE OF,E15.8,9H FEET AND,E15.8,
1
5H FEET//5X,36H IMPACT CENTER PREDICTED AT RANGE OF,E15.8,
2
21H FEET AND ALTITUDE OF,E15.8,5H FEET)
142 FORMAT (8X,90H THE ABOVE CONDITION COULD NOT BE SATISFIED, AS THE
1COMPUTED ERROR IN ALTITUDE IS EQUAL TO/6X,E15.8,29H PERCENT OF MAX
2IMUM ALTITUDE.//)
143 FORMAT (8X,91H THE ABOVE CONDITIONS COULD NOT BE SATISFIED. THE CO
1MPUTED ERROR IN TOTAL RANGE IS EQUAL TO/3X,E15.8,56H PERCENT, AND
2THE COMPUTED ERROR IN ALTITUDE IS EQUAL TO,E15.8,29H PERCENT OF MA
3XIMUM ALTITUDE.//)
144 FORMAT (8X,82H THE ABOVE CONDITION WAS SATISFIED, AND THE COMPUTED
1 ERROR IN ALTITUDE IS EQUAL TO,E15.8,11H PERCENT OF/5X,17H MAXIMUM
2 ALTITUDE//)
145 FORMAT (8X,83H THE ABOVE CONDITIONS WERE SATISFIED. THE COMPUTED E
1RROR IN TOTAL RANGE IS EQUAL TO,E15.8,9H PERCENT,/4X,48H AND THE
2COMPUTED ERROR IN ALTITUDE IS EQUAL TO,E15.8,29H PERCENT OF MAXIMU
3M ALTITUDE.//)
1 READ INPUT TAPE 2,100, NEXT(1),NEXT(2),NEXT(3),NEXT(4),KDCON,
1
NTHRST,KC,M,NXY,JN,NJR,NS,GAMMA
C
G0 TO (70,74),KDCON
C
C
C
C
READ STATEMENTS
70 IF (NEXT(1)) 72,72,71
71 READ INPUT TAPE 2,101, TABL1
72 READ INPUT TAPE 2,101, TABL2

```

```

      IF (NEXT(3)) 74,74,73
73  READ INPUT TAPE 2,101, TABL3
74  GØ TØ (75,2),NTHRST
75  IF (NEXT(1)) 77,77,404
404  READ INPUT TAPE 2,101, TRST1
      GØ TØ (76,77),M
76  READ INPUT TAPE 2,101, TMA5
77  IF (NEXT(3)) 2,2,78
78  READ INPUT TAPE 2,101, TRST2
      GØ TØ (79,2),M
79  READ INPUT TAPE 2,101, TMA52
2  READ INPUT TAPE 2,101, THDEGØ,VØ,WGT,DIA,XØ,YØ,TØ,YF
      IF (NEXT(1)) 405,405,406
405  IF (NEXT(3)) 407,407,406
406  READ INPUT TAPE 2,101, THRST,DØTM,AREA,BWGT,THR2,DØTM2,AREA2,PRESØ
      READ INPUT TAPE 2,101, TIM,DWRT(1),DWRT(2),DWRT(4),CKD,FACT
      GØ TØ 408
407  READ INPUT TAPE 2,101, DWRT(4),FACT,CKD
408  WRITE ØUTPUT TAPE 3,106

```

C  
C  
C

# CONVERSION ØF INITIAL VALUES TØ CØRRECT UNITS

```

      T = TØ
      X = XØ
      Y = YØ
      V = VØ
      THET = THDEGØ/57.29577
      THETØ = THET
      RWGT = WGT
      RMASS = WGT/32.17405
      RMASSØ = RMASS
      DØTM = DØTM/32.17405
      DØTM2 = DØTM2/32.17405
      BMASS = BWGT/32.17405
      CMACH = 0.0
      DIA = DIA/12.0
      DIASQ = DIA*DIA
      AREA = AREA/144.
      PRESØ = 144.0*PRESØ
      DWRT(3) = DWRT(1)
      IF (NS) 1001,1001,1002
1001  NS = 10
1002  IF (GAMMA) 1003,1003,1004
1003  GAMMA = 5.0
1004  IF (FACT) 1005,1005,1006
1005  FACT = 1.0
1006  GØ TØ (5092,5090),NTHRST
5090  TRST1(1,1) = TØ
      TRST1(1,2) = THRST
      TRST2(1,1) = TIM(2)
      TRST2(1,2) = THR2
      DELTHR = 0.1*TIM(1)
      DELTRS = 0.1*(TIM(3)-TIM(2))
      DØ 5091 I = 2,24
      TRST1(I,1) = TRST1(I-1,1) + DELTHR
      TRST1(I,2) = THRST
      TRST2(I,1) = TRST2(I-1,1) + DELTRS
      TRST2(I,2) = THR2
5091  CØNTINUE

```

C

C  
C

# INITIAL VALUES FOR ERROR ANALYSIS ROUTINE

```

5092 AXR = 1.9E-7
    AYR = 1.9E-7
    ATR = 2.6E-7
    AVTL = 0.0
    ATTU = 0.0
    AXTL = 0.0
    AYTL = 0.0
    EXLN = 0.0
    EYLN = 0.0
    EVLN = 0.0
    ETLN = 0.0
    EXNN = 0.0
    EYNN = 0.0
    EVNN = 0.0
    ETNN = 0.0
    EVN = 0.0
    ETN = 0.0
    EXN = 0.0
    EYN = 0.0
    YØU = 0.0
    DLFY = 0.0
    DTØNE = 0.0
    TIME = TIM(1)
    NEG = 0
    NPØS = 0
    NA = 0
    NB = 0
    NTERM = 1
    NEST = 1
    NN = 2
    CNN = NN
    NØ = 1
    NSTEP = 1
    YMAX = Y
    IF (THET) 5991,5991,5992
5991 JMP = 2
    GØ TØ 5993
5992 JMP = 1
5993 JUMP = 1
    GAM2 = .01*GAMMA
    KPHASE = 1
    DELT = V/32174.05
    DTH = DELT
    EPS = 1.0
    KU = 1
    KUK = 1
    ASSIGN 7007 TØ KAP
    ASSIGN 42 TØ NWRT
    GØ TØ (6001,6002,6001),NXY
6001 NNXY = 1
    GØ TØ 6003
6002 NNXY = 2
6003 ASSIGN 602 TØ NERR
C
    GØ TØ (80,81),KD
80 CF = FACT
    GØ TØ 82
81 CF = 0.39269908*FACT

```

```

82 J = 1
   NNN = 1
   NATMØS = 1
88 N = 1
   LINE = 2
   ASSIGN 64 TØ NCNT

```

C  
C  
C

#### INTEGRATION CØNSTANTS

```

C1 = 0.62653829 * DELT
C2 = -0.55111241 * DELT
C3 = 1.4072559 * DELT
C4 = -0.48268182 * DELT
EPSLØN = 0.001 * DELT
WRIT = T-EPSLØN

```

C

```

   IF (NEXT(N))409,409,410
409 NNN = 2
   GØ TØ 50
410 WRITE ØUTPUT TAPE 3,114
61 WRITE ØUTPUT TAPE 3,109
   WRITE ØUTPUT TAPE 3,110

```

C

```

3 DØ 45 K = 1,3
   GØ TØ NCNT,(62,64)
62 WRITE ØUTPUT TAPE 3,108
   WRITE ØUTPUT TAPE 3,110
   ASSIGN 64 TØ NCNT
   CØNTINUE

```

C

```

64 CALL ATMØS(Y,V)
   GØ TØ (10,29),KDCØN
10 GØ TØ (17,25,21,25),N

```

C  
C  
C  
C  
C

#### TABLE LØØK-UPS FØR DRAG CØEFFICIENT

#### DURING FIRST BURNING STAGE

```

17 CALL TABLE(TABL1,CMACH,CKD,24)
   GØ TØ 29

```

C  
C  
C

#### DURING SECØND BURNING STAGE

```

21 CALL TABLE(TABL3,CMACH,CKD,24)
   GØ TØ 29

```

C  
C  
C

#### DURING FREE-FLIGHT

```

25 CALL TABLE(TABL2,CMACH,CKD,24)
   CØNTINUE
29 GØ TØ (95,96),NTHRST
95 GØ TØ (200,96,300,96),N

```

C  
C  
C

#### THRUST TABLE FØR FIRST BURNING STAGE

```

200 CALL TABLE(TRST1,T,THRST,24)
   GØ TØ (18,96,96),K
18 GØ TØ (19,96),M
19 CALL TABLE(TMAS,T,RMASS,24)
   RMASS = RMASS/32.17405

```

G0 T0 96

C  
C  
C

# THRUST TABLE FOR SECOND BURNING STAGE

```
300 CALL TABLE(TRST2,T,THRST,24)
    G0 T0 (22,96,96),K
    22 G0 T0 (23,96),M
    23 CALL TABLE(TMAS2,T,RMASS,24)
    RMASS = RMASS/32.17405
    CONTINUE
```

C  
C  
C

## DERIVATIVES

```
96 CCD = CF*CKD
    DRAG = CCD*RH0*V*V*DIASQ
    DOM = DRAG/RMASS
    CCOS = COSF(THET)
    CSIN = SINF(THET)
    XD0T(K) = V*CCOS
    YD0T(K) = V*CSIN
    G0 T0 (501,502,501,502),N
    501 PRESS = PRSB*ARGU
    THRUST = THRST + AREA*(PRES0-PRESS)
    VD0T(K) = (THRUST/RMASS) - GRAV*CSIN - DOM
    RWGT = 32.17405*RMASS
    G0 T0 503
    502 VD0T(K) = -GRAV*CSIN - DOM
    503 THD0T(K) = -GRAV*CCOS/V
```

C

```
34 G0 T0 (35,43,44),K
35 G0 T0 NWRT,(36,39,41,42)
36 IF(DWRT(N)) 37,37,38
37 ASSIGN 41 T0 NWRT
    G0 T0 41
38 ASSIGN 39 T0 NWRT
    CONTINUE
39 IF(WRIT-T) 40,40,42
40 WRIT = T+DWRT(N)-EPSLON
41 THDEG = 57.29577*THET
    THDDT = 57.29577*THD0T(1)
    WRITE OUTPUT TAPE 3,111, T,X,Y,V,THDEG,CMACH,CCD,THRUST,RWGT,RH0
    WRITE OUTPUT TAPE 3,112, XD0T(1),YD0T(1),VD0T(1),THDDT,DRAG,PRESS
    LINE = LINE + 1
    IF (28-LINE) 63,63, 42
63 ASSIGN 62 T0 NCNT
    LINE = 1
    CONTINUE
```

C  
C  
C

## MODIFIED THIRD ORDER RUNGE-KUTTA INTEGRATION

```
42 X = X + C1*XD0T(K)
    Y = Y+C1*YD0T(K)
    V = V+C1*VD0T(K)
    THET = THET+C1*THD0T(K)
    G0 T0 45
```

C

```
43 X = X + C2*XD0T(K)
    Y = Y+C2*YD0T(K)
    V = V+C2*VD0T(K)
    THET = THET+C2*THD0T(K)
```

```

      GØ TØ 45
C
44 X = X + C3*XDØT(K-1) + C4*XDØT(K)
   Y = Y+ C3*YDØT(K-1)+C4*YDØT(K)
   V = V+ C3*VDØT(K-1)+C4*VDØT(K)
   THET = THET+C3*THDØT(K-1)+C4*THDØT(K)
   T = T+DELT
   RMASS = RMASS-DØTM*DELT
45 CØNTINUE
C
C      H.KØPP ERRØR ANALYSIS RØUTINE (SIMPLIFIED)
C
      NSTEP = NSTEP + 1
      GØ TØ (599,599,92,92),KU
599 IF (NN - NSTEP) 601,601,92
601 GØ TØ (1311,92),NTERM
1311 IF (Y-YØU) 92,1312,1312
1312 GØ TØ NERR,(602,603,605)
C
602 ASSIGN 603 TØ NERR
      NSTEP = NN - 1
      VV = V
      THH = THET
      XX = X
      YY = Y
      RMT = RMASS
      TT = T
      DDTT = DELT
      GØ TØ 3
603 ASSIGN 605 TØ NERR
      ASSIGN 42 TØ NWRT
      NSTEP = NN - 2
      DH = DELT
      VH = V
      THH = THET
      XH = X
      YH = Y
C
C      CØMPUTATION ØF PRØPAGATION ERRØR CØEFFICIENTS
C
      C = (2.0*RHØ*CCD*DIASQ*V*V)/(RMASS*GRAV)
      CSQ = C*C
      PC = CØSF(THET)
      PS = SINF(THET)
      PS = ABSF(PS)
      A13 = PC*(1.03 - .014*C + .0003*CSQ)
      A14 = 1.2*PS + .28 - .0001*C
      A23 = (PS+.08)*(1.0-.02*C+.0004*CSQ)
      A44 = 1.2*PS + .21 + .0003*C
      PCP7 = PC + .07
      A24 = A44*PCP7
      A33 = .019 +C*(-1.1 + C*(.04 - .0002*C))
      A34 = (PC+.1)*(1.02+.018*C)
      A43 = PCP7*(1.4-.02*C+.0003*CSQ)
C
      DELTA = A33*A44 - A34*A43
      AVR = (THRUST/RWGT)*2.9E-7 + C*3.3E-7 + 2.0E-7
      AFT = A33-A44
      ARGM = AFT*AFT + 4.0*A34*A43
      EPS = 0.5*(A33 + A44 + SQRTF(ARGM))

```

GKK = (EPS-A33)/A34  
 EPS = GRAV\*EPS/V  
 V = VV  
 THET = THTH  
 X = XX  
 Y = YY  
 T = TT  
 RMASS = RMT  
 DELT = 0.5\*DELT

C

604 C1 = 0.62653829\*DELT  
 C2 = -0.55111241\*DELT  
 C3 = 1.4072559\*DELT  
 C4 = -0.48268182\*DELT  
 GØ TØ 3

605 EH = EPS\*DH  
 ASSIGN 602 TØ NERR  
 CLAM = 1.0 + EH  
 EHØ2 = 0.5\*EH\*EH

C

C

C

COMPUTATION ØF TRUNCATION ERROR CØEFFICIENTS

A = ABSF(VH-V) - DH\*((THRUST/RMASS)\*11.0E-8 + GRAV\*7.0E-8 + DØM\*  
 1 19.0E-8)

IF (A) 5001,5002,5002

5001 A = 0.0

5002 B = ABSF(THH-THET) - (GRAV\*DH\*1.0E-8)/V

IF (B) 5003,5004,5004

5003 B = 0.0

5004 DH3 = DH\*\*3

CC = 1.75\*V\*DH3

AVT = (A\*ABSF(A33) + VH\*A34\*B)/CC

IF (AVT-AVTL) 4002,4001,4001

4001 AVTL = 0.8\*AVT

GØ TØ 4003

4002 AVT = AVTL

AVTL = 0.8\*AVT

4003 CØNTINUE

ATT = (A43\*A + VH\*A44\*B)/CC

IF (ATT-ATTL) 4005,4004,4004

4004 ATTL = 0.8\*ATT

GØ TØ 4006

4005 ATT = ATTL

ATTL = 0.8\*ATT

4006 CØNTINUE

PHB = A44\*AVT-A34\*ATT

PHBB = A44\*AVR - A34\*ATR

PSB = -A43\*AVT + A33\*ATT

PSBB = -A43\*AVR + A33\*ATR

EVØV = EVN/VH

VH4 = VH\*DH\*DH3

TH3 = 2.0\*DH3

QQ = 1.1428571/VH4

DHV7 = DH\*V\*7.0E-8

DX2 = ABSF(XH-X) - DHV7

IF (DX2) 5005,5006,5006

5005 DX2 = 0.0

5006 AXT = QQ\*DX2

IF (AXT-AXTL) 4008,4007,4007

4007 AXTL = 0.8\*AXT

```

      GØ TØ 4009
4008 AXT = AXTL
      AXTL = 0.8*AXT
4009 CØNTINUE
      DY2 = ABSF(YH-Y) - DHV7
      IF (DY2) 5007,5008,5008
5007 DY2 = 0.0
5008 AYT = QQ*DY2
      IF (AYT-AYTL) 4011,4010,4010
4010 AYTL = 0.8*AYT
      GØ TØ 6005
4011 AYT = AYTL
      AYTL = 0.8*AYT

```

C  
C  
C

# TRAJECTORY ESTIMATES FOR THRUST PHASES

```

6005 QYK = Y
      QYH = Y
      QXK = X
      QXH = X
      QVK = V
      QVH = V
      QTHK = THET
      QMH = RMASS
      DMDØT = DØTM
      GØ TØ (6006,6026,6008,6028),NEST
6006 DØ 6366 II = 1,30
      IF (TRST1(II,1) - T) 6366,6166,6266
6166 QTK = TRST1(II,2)
      QTH = TRST1(II+1,2)
      QMH = TMAS(II+1,2)/32.17405
      CØNT = TRST1(II+1,1) - TRST1(II,1)
      GØ TØ 6466
6266 QTK = TRST1(II-1,2) + ((T-TRST1(II-1,1))/(TRST1(II,1)-TRST1(II-1,1))) * (TRST1(II,2)-TRST1(II-1,2))
      QTH = TRST1(II,2)
      QMH = TMAS(II,2)/32.17405
      CØNT = TRST1(II,1) - T
      GØ TØ 6466
6366 CØNTINUE
6466 KLER = 1
      GØ TØ (6010,6011),M
6008 DØ 6388 II = 1,30
      IF (TRST2(II,1) - T) 6388,6188,6288
6188 QTK = TRST2(II,2)
      QTH = TRST2(II+1,2)
      QMH = TMAS2(II+1,2)/32.17405
      CØNT = TRST2(II+1,1) - TRST2(II,1)
      GØ TØ 6488
6288 QTK = TRST2(II-1,2) + ((T-TRST2(II-1,1))/(TRST2(II,1)-TRST2(II-1,1))) * (TRST2(II,2) - TRST2(II-1,2))
      QTH = TRST2(II,2)
      QMH = TMAS2(II,2)/32.17405
      CØNT = TRST2(II,1) - T
      GØ TØ 6488
6388 CØNTINUE
6488 KLER = 2
      DMDØT = DØTM2
      GØ TØ (6010,6011),M
6010 QM = (QMH-RMASS)/CØNT

```



```

      G0 T0 6012
6011 QM = -DMD0T
      QMH = RMASS - DMD0T*C0NT
6012 QT = (QTH - THRST)/C0NT
      ALPHA = GRAV*SINF(THET)
      BETA = RH0*DIASQ*QVK*CKD*CF
      AQT0B = ALPHA + QT/BETA
      QEX = BETA/QM
      UN = QM + BETA
      QVH = QTH/BETA - (QMH*AQT0B/UN) + (QVK + AQT0B*RMASS/UN - THRST/
1      BETA)*((RMASS/QMH)**QEX)
      PT3V = 0.4*(QVH+QVK)*C0NT
      CSKAY = C0SF(QTHK)
      QXK = QXK + PT3V*CSKAY
      QYK = QYK + PT3V*SINF(QTHK)
      QTHK = QTHK - 2.0*GRAV*CSKAY*C0NT/(QVK+QVH)
      QVK = QVH
      II = II + 1
6013 D0 6021 I = II,30
      CALL ATM0S(QYK,QVK)
      G0 T0 (6014,6016),KLER
6014 QTK = QTH
      QTH = TRST1(I,2)
      C0NT = TRST1(I,1) - TRST1(I-1,1)
      TM0UT = TRST1(I,1)
      G0 T0 (6614,6615),KDC0N
6614 CALL TABLE(TABL1,CMACH,CKD,24)
6615 G0 T0 (6015,6019),M
6015 QMK = QMH
      QMH = TMA5(I,2)/32.17405
      G0 T0 6018

```

C

```

6016 QTK = QTH
      QTH = TRST2(I,2)
      C0NT = TRST2(I,1) - TRST2(I-1,1)
      TM0UT = TRST2(I,1)
      G0 T0 (6616,6617),KDC0N
6616 CALL TABLE(TABL3,CMACH,CKD,24)
6617 G0 T0 (6017,6019),M
6017 QMK = QMH
      QMH = TMA52(I,2)/32.17405
6018 QM = (QMH-QMK)/C0NT
      G0 T0 6020
6019 QM = -DMD0T
      QMK = QMH
      QMH = QMK - DMD0T*C0NT
6020 QT = (QTH-QTK)/C0NT
      SNKAY = SINF(QTHK)
      CSKAY = C0SF(QTHK)
      ALPHA = GRAV*SNKAY
      BETA = RH0*DIASQ*QVK*CKD*CF
      AQT0B = ALPHA + QT/BETA
      UN = QM + BETA
      QEX = BETA/QM
      QVH = (QTH/BETA) - (QMH*AQT0B/UN) + (QVK + (AQT0B*QMK/UN) - (QTK/
1      BETA))*((QMK/QMH)**QEX)
      PT3V = 0.4*(QVH+QVK)*C0NT
      QXK = QXK + PT3V*CSKAY
      QYK = QYK + PT3V*SNKAY
      QTHK = QTHK - 2.0*GRAV*CSKAY*C0NT/(QVK+QVH)

```

```

      QVK = QVH
      IF (TIME-TMOUT-CØNT*1.0E-4) 6022,6022,6021
6021 CØNTINUE
6022 GØ TØ (6024,6028),KLER
6024 IF (NEXT(2))6028,6028,6025
C
C      TRAJECTØRY ESTIMATE FØR INTERMEDIATE BALLISTIC PHASE
C
6025 QMK = QMH - BMASS
      CØNT = TIM(2) - TIM(1)
      GØ TØ 6027
6026 QMK = RMASS
      CØNT = TIM(2) - T
6027 PT6V = 0.6*QVK*CØNT
      CSKAY = CØSF(QTHK)
      SNKAY = SINF(QTHK)
      QXK = QXK + PT6V*CSKAY
      QYK = QYK + PT6V*SNKAY
      QTHK = QTHK - (GRAV*CSKAY/QVK)*CØNT
      GØ TØ (6627,6628),KDCØN
6627 CALL TABLE(TABL2,CMACH,CKC,24)
6628 QVK = QVK + (-GRAV*CSKAY - RHØ*CF*CKD*QVK*QVK*DIASQ/QMK)*CØNT
      KLER = 2
      II = 2
      DMDØT = DØTM2
      QTH = TRST2(II-1,2)
      GØ TØ 6013
C
C      TRAJECTØRY ESTIMATE FØR TERMINAL BALLISTIC PHASE
C
6028 U = SINF(QTHK)
      QDØTY = QVK*U
      TMTN = (QDØTY + SQRTF(QDØTY*QDØTY + 2.0*GRAV*QYK))/GRAV
      GØ TØ (6129,6128,6129),NXY
6128 GØ TØ (6129,5014),JMP
6129 CSK = CØSF(QTHK)
      QDØTX = 0.6*QVK*CSK
      PLUS = 1.0/(QVK*CSK)
      GØ TØ (6227,6228),KDCØN
6227 CALL ATMØS(QYK,QVK)
      CALL TABLE(TABL2,CMACH,CKC,24)
6228 BET = 0.0023769*DIASQ*QVK*CKD*CF/32.17405
      SNØCS = U/CSK
      DU = 0.05*(U+0.9995)
      DUØG = DU/32.17405
C
6229 IF (QYK-5.8E4) 6029,6030,6031
6029 BØG = BET
      GØ TØ 6043
6030 BØG = 0.1*BET
      GØ TØ 6043
6031 IF (QYK-1.0E5) 6030,6032,6033
6032 BØG = 0.01*BET
      GØ TØ 6043
6033 IF (QYK-1.6E5) 6032,6034,6035
6034 BØG = 0.001*BET
      GØ TØ 6043
6035 IF (QYK-2.3E5) 6034,6036,6037
6036 BØG = BET*1.0E-4
      GØ TØ 6043

```

```

6037 IF (QYK-3.0E5) 6036,6038,6039
6038 BØG = BET*1.0E-6
      GØ TØ 6043
6039 IF (QYK-4.0E5) 6038,6040,6041
6040 BØG = BET*1.0E-8
      GØ TØ 6043
6041 IF (QYK-6.0E5) 6040,6042,6042
6042 BØG = BET*1.0E-13
C
6043 AA = BØG*SNØCS + PLUS
      ØMU = (1.0+U)*(1.0-U)
      RØØT = SQRTF(ØMU)
      AU = (RØØT*AA - BØG*U)**2
C
      QDØTY = U/(ØMU*AU)
      QYH = QYK + 0.8*QDØTY*DUØG
      QDØTX = 1.0/(AU*RØØT)
      QXH = QXK + QDØTX*DUØG
      GØ TØ (6444,6046),JMP
6444 GØ TØ (6044,6046),JUMP
6044 IF (QYH - QYK) 6045,6045,6046
6045 YMAX = QYK
      JUMP = 2
6046 IF (QYH-YF) 6049,6048,6047
6047 QYK = QYH
      QXK = QXH
      U = U - DU
      IF (1.0+U) 6048,6048,6229
C
6048 XMAX = QXH
      GØ TØ 5014
6049 XMAX = QXK + (QXH-QXK)*(QYK-YF)/(QYK-QYH)
C
C      ESTIMATES ØF ERRØRS ØVER N STEPS
C
5014 JUMP = 1
      IF (NN-NSTEP) 8002,8002,8001
8001 CNN = NSTEP
8002 CLAMN = CLAM**CNN
      GL = (CLAMN-1.0)/(CLAM-1.0)
      VHH = VH*DH
      PHH = ABSF(PHB*DH3 + PHBØ)
      PSH = ABSF(PSB*DH3 + PSBØ)
      IF (PHH-PSH) 4013,4014,4014
4013 CØNE = PSH/ABSF(DELTA)
      GØ TØ 4015
4014 CØNE = PHH/ABSF(DELTA)
4015 ETØK = ETN/ABSF(GKK)
      IF (EVØV-ETØK) 4016,4017,4017
4016 CTWØ = ETØK
      GØ TØ 4018
4017 CTWØ = EVØV
4018 CTHR = A13 + GKK*A14
      CFØR = A23 + GKK*A24
      C12 = CØNE + CTWØ
      EVLN = V*(-CØNE + CLAMN*C12)
      ETLN = GKK*EVLN/V
      EXLN = EXN + VHH*(CNN*(AXT*DH3 + AXR) - CØNE*CTHR + CTHR*C12*GL)
      EYLN = EYN + VHH*(CNN*(AYT*DH3 + AYR) - CØNE*CFØR + CFØR*C12*GL)
C

```

```

      IF (NN-NSTEP) 8003,8003,8004
8003 EVN = 0.5*(EVLN + EVNN)
      ETN = 0.5*(ETLN + ETNN)
      EXN = 0.5*(EXLN + EXNN)
      EYN = 0.5*(EYLN + EYNN)
      GO TO 8005

C
8004 EVN = EVLN
      ETN = ETLN
      EXN = EXLN
      EYN = EYLN
8005 GO TO (7111,7222,7333),KPHASE

C
C      ERROR ANALYSIS INITIALIZATION FOR START OF PHASE
C
7222 KPHASE = 3
      NN = 4
      NSTEP = 2
      CNN = 2.0
      AVTL = 0.0
      ATTL = 0.0
      AXTL = 0.0
      AYTL = 0.0
      EVNN = 0.0
      ETNN = 0.0
      EXNN = 0.0
      EYNN = 0.0
      EXAVE = EXN
      EYAVE = EYN
      EVAVE = EVN
      ETAVE = ETN
      T00 = T
      X00 = X
      Y00 = Y
      V00 = V
      TH00 = THET
      RM00 = RMASS
      DTH = V/32174.05
      ASSIGN 42 TO NWRT
      GO TO 637

C
7333 KPHASE = 1
      T = T00
      X = X00
      Y = Y00
      V = V00
      THET = TH00
      RMASS = RM00
      EXN = EXAVE
      EYN = EYAVE
      EVN = EVAVE
      ETN = ETAVE
      ASSIGN 36 TO NWRT
      GO TO 609

C
7111 IF (NN-2) 7001,7001,7002
7001 T = T0
      X = X0
      Y = Y0
      V = V0

```

```

      THET = THET0
      RMASS = RMASS0
      EXN = 0.0
      EYN = 0.0
      EVN = 0.0
      ETN = 0.0
7002 CNN = NS
      NN = NS
      NSTEP = 1
      ASSIGN 36 TO NWRT
      IF (SENSE SWITCH6) 3004,3006
3004 CALL PDUMP(ZM,A13,1)
3006 CONTINUE
C
C      ESTABLISHING STARTING VALUES FOR DOUBLE FALSE POSITION
C
609 KLK = 1
      DT = 0.035*VH/GRAV
610 CLAM = 1.0 + EPS*DT
      GNN = TMTN/DT
      CLAMN = CLAM**GNN
      GL = (CLAMN-1.0)/(CLAM-1.0)
      DT3 = DT**3
      PHT = ABSF(PHB*DT3 + PH88)
      PST = ABSF(PSB*DT3 + PS88)
      IF (PHT-PST) 4020,4021,4021
4020 C0NE = PST/ABSF(DELTA)
      GO TO 4022
4021 C0NE = PHT/ABSF(DELTA)
4022 ET0K = ETN/ABSF(GKK)
      EV0V = EVN/VH
      IF (EV0V-ET0K) 4023,4024,4024
4023 CTW0 = ET0K
      GO TO 4025
4024 CTW0 = EV0V
4025 C12 = C0NE + CTW0
      VHH = VH*DT
      GO TO (4026,4027),NNXY
4026 EXNN = EXN + VHH*(GNN*(AXT*DT3 + AXR) - C0NE*CTHR + CTHR*C12*GL)
      XIDT = EXNN - GAM2*XMAX
      GO TO 4028
4027 EYNN = EYN + VHH*(GNN*(AYT*DT3 + AYR) - C0NE*CF0R + CF0R*C12*GL)
      XIDT = EYNN - GAM2*YMAX
C
4028 GO TO (611,615,615,615,617),KLK
611 IF (XIDT) 612,613,613
612 DTH = DT
      GO TO 630
613 XID2 = XIDT
      DT2 = DT
614 DT = 0.1*DT
      KLK = KLK + 1
      GO TO 610
615 IF (XIDT) 616,614,614
616 XID1 = XIDT
      DT1 = DT
      GO TO 618
617 GAM2 = 2.0*GAM2
      GO TO 609
C

```

C  
C  
C

# DOUBLE FALSE POSITION ROUTINE FOR F(DELTA)

```

618 DT0 = (DT1*XID2 - DT2*XID1)/(XID2 - XID1)
    GNN = TMTN/DT0
    CLAM = 1.0 + EPS*DT0
    CLAMN = CLAM**GNN
    DT3 = DT0**3
    VHH = VH*DT0
    GL = (CLAMN-1.0)/(CLAM-1.0)
    PHT = ABSF(PH0*DT3 + PH08)
    PST = ABSF(PS0*DT3 + PS08)
    IF (PHT-PST) 4030,4031,4031
4030 C0NE = PST/ABSF(DELTA)
    G0 T0 4032
4031 C0NE = PHT/ABSF(DELTA)
4032 ET0K = ETN/ABSF(GKK)
    IF (EV0V-ET0K) 4033,4034,4034
4033 CTW0 = ET0K
    G0 T0 4035
4034 CTW0 = EV0V
4035 C12 = C0NE + CTW0
    G0 T0 (5020,5021),NNXY
5020 EXNN = EXN + VHH*(GNN*(AXT*DT3 + AXR) - C0NE*CTHR + CTHR*C12*GL)
    XID0 = EXNN - GAM2*XMAX
    G0 T0 5022
5021 EYNN = EYN + VHH*(GNN*(AYT*DT3 + AYR) - C0NE*CF0R + CF0R*C12*GL)
    XID0 = EYNN - GAM2*YMAX
5022 DIFH = (DT1-DT2)/DT2
    IF (0.05-ABSF(DIFH)) 661,660,660
    660 G0 T0 (5025,5026),NNXY
5025 G0 T0 (5029,5029,5027),NXY
5026 G0 T0 (5029,5029,5028),NXY
5027 KLK = 1
    DT = DT0
    NNXY = 2
    G0 T0 610
5028 NNXY = 1
5029 DTH = DT0
    NEG = 0
    NP0S = 0
    G0 T0 630

C
661 IF (XID0) 619,620,620
619 NEG = NEG + 1
    NP0S = 0
    G0 T0 (621,626),NEG
620 NP0S = NP0S + 1
    NEG = 0
    G0 T0 (621,627),NP0S
621 IF (XID0) 622,623,623
622 DT1 = DT0
    XID1 = XID0
    G0 T0 618
623 DT2 = DT0
    XID2 = XID0
    G0 T0 618

C
626 IF (XID1) 627,628,628
627 XID2 = XID2/2.0

```

```

      NEG = 0
      NPDS = 0
      G0 T0 618
628 XID1 = XID1/2.0
      NEG = 0
      NPDS = 0
      G0 T0 618
629 IF (XID1) 628,627,627
C
630 G0 T0 (632,632,632,631),N
631 NN = NS
      CNN = NS
      KPHASE = 1
      NSTEP = 1
      G0 T0 636
632 CNN = NS
      IF (CNN*CTH+T - TIM(N)) 636,636,633
633 CNN = (TIM(N)-T)/DTH
      NN = CNN
      CCN = NN
      IF (CNN-CCN) 634,634,635
634 CNN = CCN
      G0 T0 6355
635 CNN = CCN + 1.0
6355 NSTEP = 1
      NN = CNN
6356 NEST = NEST + 1
      IF (NEXT(NEST)) 6356,6356,6357
6357 KPHASE = 2
      DTH = (TIM(N)-T)/CNN
636 CLAMN = CLAM*CNN
      GL = (CLAMN-1.0)/(CLAM-1.0)
      EVNN = VH*(-CONE + CLAMN*C12)
      ETNN = GKK*EVNN/VH
      EXNN = EXN + VHH*(CNN*(AXT*DT3 + AXR) - CONE*CTHR + CTHR*C12*GL)
      EYNN = EYN + VHH*(CNN*(AXT*DT3 + AYR) - CONE*CFOR + CFOR*C12*GL)
C
      G0 T0 (7006,7003,7006,637),KU
7003 Y2U = YF + EYN
      DLEY = (EYNN - EYN)/CNN
      ERRA = -DLEY
7006 EV(N0) = EVN
      ET(N0) = ETN*57.29577
      EX(N0) = EXN
      EY(N0) = EYN
      TN(N0) = TT + DH
      XN(N0) = XH
      YN(N0) = YH
      VN(N0) = VH
      THN(N0) = THH * 57.29577
      N0 = N0 + 1
637 DELT = DTH
      C1 = 0.62653829*DELT
      C2 = -0.55111241*DELT
      C3 = 1.4072559*DELT
      C4 = -0.48268182*DELT
      G0 T0 (92,92,49),KPHASE
C
49 THDEG = 57.29577*THET
      THDGT = 57.29577*THDGT(3)

```

```

RWGT = 32.17405 * RMASS
WRITE OUTPUT TAPE 3,111, T,X,Y,V,THDEG,CMACH,CCD,THRUST,RWGT,RH0
WRITE OUTPUT TAPE 3,112, XD0T(1),YD0T(1),VD0T(1),THDDT,DRAG,PRESS
50 N = N+1
   IF(NEXT(N)) 50,50,51
51 G0 T0 (3,55,56,59,7020),N
C
55 THRUST = 0.0
   D0TM = 0.0
   AREA = 0.0
   RMASS = RMASS-BMASS
   RM00 = RMASS
   RWGT = 32.17405 * RMASS
   G0 T0 (801,802),NNN
801 WRITE OUTPUT TAPE 3,115
   G0 T0 999
802 WRITE OUTPUT TAPE 3,121
   NNN = 1
   G0 T0 999
C
56 THRST = THR2
   D0TM = D0TM2
   AREA = AREA2/144.0
   KASE = 2
   G0 T0 (803,804),NNN
903 WRITE OUTPUT TAPE 3,116
   G0 T0 999
804 WRITE OUTPUT TAPE 3,122
   NNN = 1
   G0 T0 999
C
59 THRUST = 0.0
   D0TM = 0.0
   AREA = 0.0
   G0 T0 (805,806),NNN
805 WRITE OUTPUT TAPE 3,117
   G0 T0 999
806 WRITE OUTPUT TAPE 3,123
   NNN = 1
C
999 EPSL0N = 0.001*DELT
   NEST = N
   TIME = TIM(N)
   ASSIGN 42 T0 NWRT
   ASSIGN 64 T0 NCNT
   LINE = 2
   WRITE OUTPUT TAPE 3,109
   WRITE OUTPUT TAPE 3,110
   G0 T0 3
C
C
C
TEST FOR END OF TRAJECTORY
C
92 G0 T0 KAP,(7007,7010,7013)
7007 IF (YD0T(1)) 7008,3,3
7008 KU = 2
   ASSIGN 7010 T0 KAP
   YMAX = Y
   JMP = 2
7010 IF (Y-Y0U) 7012,7011,7011
7011 Y0U = Y0U + DLEY

```



```

      YLST = Y
      GØ TØ 3
7012 ASSIGN 42 TØ NWRT
      NTERM = 2
      YØNE = Y
      YTWØ = YLST
      DTTWØ = -DELT
      DELT3 = -DTTWØ*(YØNE-YØU)/(YTWØ-YØNE)
      DELT = DELT3
      ASSIGN 7013 TØ KAP
      GØ TØ 604
7013 IF(Y-YØU) 7014,7015,7015
7014 YØNE = Y
      NB = 0
      NA = NA + 1
      IF (NA-2) 6081,6080,6080
6080 YTWØ = YØU + 0.5*(YTWØ-YØU)
6081 DTØNE = DELT3
      DELT3 = ((YTWØ-YØU)*DTØNE - (YØNE-YØU)*DTTWØ)/(YTWØ-YØNE)
      DELT = DELT3 - DTØNE
      GØ TØ 7016
7015 YTWØ = Y
      NA = 0
      NB = NB + 1
      IF (NB-2)6083,6082,6082
6082 YØNE = YØU + 0.5*(YØNE-YØU)
6083 DTTWØ = DELT3
      DELT3 = ((YTWØ-YØU)*DTØNE - (YØNE-YØU)*DTTWØ)/(YTWØ-YØNE)
      DELT = DELT3 - DTTWØ
7016 IF (YTWØ-YØNE-.01*EYN) 7017,7017,604
7017 GØ TØ (7018,7018,7019,7020),KU
7018 XUNØ = X
      KU = 3
      NN = NS
      CNN = NSTEP
      NSTEP = 1
      TT = T
      XH = X
      THH = THET
      YH = YØU
      YØU = YF
      DLEY = 0.0
      VH = V
      YLST = Y
      DTØNE = 0.0
      DH = 0.0
      ASSIGN 7010 TØ KAP
      GØ TØ 6005
7019 EV(NØ) = EVN
      ET(NØ) = ETN*57.29577
      EX(NØ) = EXN
      EY(NØ) = EYN
      TN(NØ) = T
      XN(NØ) = X
      YN(NØ) = Y
      VN(NØ) = V
      THN(NØ) = THET * 57.29577
      KU = 4
      NN = NS
      CNN = NSTEP

```

```

NSTEP = 1
TT = T
XH = X
THH = THET
YH = YØU
VH = V
YLST = Y
DH = 0.0
YØU = YF-EYN
DLEY = ERRA
DTØNE = 0.0
ASSIGN 7010 TØ KAP
THDEG = THET*57.29577
WRITE ØUTPUT TAPE 3,111, T,X,Y,V,THDEG,CMACH,CCD,THRUST,RWGT,RHØ
401 WRITE ØUTPUT TAPE 3,113, NJR
WRIT = T + 1000.
ASSIGN 42 TØ NWRT
GØ TØ 6005

```

C

```

7020 LINE = 27
XDØS = X
WRITE ØUTPUT TAPE 3,126
WRITE ØUTPUT TAPE 3,127
WRITE ØUTPUT TAPE 3,128
GØ TØ (5051,5053,5052),NXY
5051 WRITE ØUTPUT TAPE 3,131, GAMMA
PERX = 100.*EX(NØ)/XN(NØ)
GØ TØ 5054
5052 WRITE ØUTPUT TAPE 3,131, GAMMA
5053 WRITE ØUTPUT TAPE 3,132, GAMMA
PERY = 100.*EY(NØ)/YMAX
5054 IF (GAMMA-100.*GAM2) 5055,5056,5056
5055 GØ TØ (5551,5552,5553),NXY
5551 WRITE ØUTPUT TAPE 3,130, PERX
GØ TØ 5057
5552 WRITE ØUTPUT TAPE 3,142, PERY
GØ TØ 5057
5553 WRITE ØUTPUT TAPE 3,143, PERX,PERY
GØ TØ 5057
5056 GØ TØ (5554,5555,5556),NXY
5554 WRITE ØUTPUT TAPE 3,129, PERX
GØ TØ 5057
5555 WRITE ØUTPUT TAPE 3,144, PERY
GØ TØ 5057
5556 WRITE ØUTPUT TAPE 3,145, PERX,PERY
5057 WRITE ØUTPUT TAPE 3,133
WRITE ØUTPUT TAPE 3,134, XN(NØ),EX(NØ),YN(NØ),EY(NØ),THN(NØ),
1 ET(NØ),VN(NØ),EV(NØ)
WRITE ØUTPUT TAPE 3,135
WRITE ØUTPUT TAPE 3,136, XØ,YØ,THDEGØ,VØ
WRITE ØUTPUT TAPE 3,137
WRITE ØUTPUT TAPE 3,139
NØØ = NØ - 1
DØ 5059 KE =2,NØØ
WRITE ØUTPUT TAPE 3,140, TN(KE),XN(KE),YN(KE),THN(KE),VN(KE),
1 EX(KE),EY(KE),ET(KE),EV(KE)
LINE = LINE + 3
IF (56-LINE) 5058,5058,5059
5058 WRITE ØUTPUT TAPE 3,138
WRITE ØUTPUT TAPE 3,139

```

```
LINE = 5
5059 CONTINUE
      GO TO (5060,5060,5060,5060,5061),N
5060 WRITE OUTPUT TAPE 3,141, XUN0,XD0S,XN(N0),YF
5061 NJR = NJR + 1
      JN = JN-1
      IF (JN) 1,1,2
C
      END
```

## APPENDIX II

This appendix contains output for the sample calculation depicted by Figure 2. The input for this computation is illustrated in Section C. The first portion of the output consists of a table of range, altitude, speed and angle as a function of time. Also included are the time derivatives of these quantities, the mach number, the drag coefficient, the thrust, vehicle weight and drag, the air density, and the air pressure when required.

The second section of the output is devoted to the error analysis routine. This begins with a description of the error specification and provides the estimated error for comparison. A table of range error (feet), altitude error (feet), speed error (feet/second), and angular error (degrees) as a function of time follow. This page is terminated by bounds for the impact range which are based upon a consideration of the numerical error envelope surrounding the computed trajectory.

COMPUTING AND ANALYSIS SECTION  
TWO-DIMENSIONAL, TWO-STAGE ROCKET OR BALLISTIC TRAJECTORY PROGRAM  
\*WITH 1959 ANDC STANDARD ATMOSPHERE\*

TIME	RANGE X-DERIV	ALTITUDE Y-DERIV	VELOCITY V-DERIV	FREE-FLIGHT ΘF THETA TH-DERIV	MAIN STAGE MACH	KD	THRUST	WEIGHT DRAG	DENSITY PRESSURE
-0.	-0.	-0.	1000.000	45.000	0.8957	0.0950	0.	100.000	0.23769E-02
0.423	707.107	707.107	-83.772	-1.304	0.8655	0.0972	0.	189.662	0.
0.846	295.453	292.596	965.299	44.436	0.8365	0.0994	0.	100.000	0.23566E-02
1.270	689.258	675.814	-80.238	-1.364	0.8087	0.1015	0.	179.378	0.23374E-02
1.693	583.524	572.190	932.065	43.845	0.7821	0.1026	0.	169.564	0.
2.116	672.215	645.656	-76.842	-1.426	0.7567	0.1034	0.	100.000	0.23191E-02
2.539	864.546	819.251	900.238	43.228	0.7325	0.1041	0.	160.222	0.
2.963	655.944	616.576	-73.584	-1.492	0.7094	0.1048	0.	100.000	0.23017E-02
3.386	1138.846	1094.229	869.827	42.582	0.6874	0.1054	0.	150.182	0.
3.809	640.460	588.567	-70.088	-1.560	0.6664	0.1060	0.	100.000	0.22853E-02
4.232	1406.773	1337.588	840.901	41.907	0.6463	0.1066	0.	140.370	0.
4.657	625.824	561.657	-66.650	-1.631	0.6182	0.1075	0.	100.000	0.22696E-02
5.082	1668.676	1569.778	813.379	41.201	0.5919	0.1080	0.	131.332	0.
5.507	611.989	535.776	-63.445	-1.705	0.5673	0.1082	0.	122.998	0.
5.932	1924.884	1791.219	787.169	40.463	0.5443	0.1083	0.	100.000	0.22407E-02
6.357	598.894	510.843	-60.450	-1.781	0.5228	0.1084	0.	115.304	0.
6.782	2175.696	2002.295	762.186	39.693	0.5027	0.1086	0.	100.000	0.22274E-02
7.207	586.487	486.786	-57.643	-1.861	0.4840	0.1087	0.	108.194	0.
7.632	2421.394	2203.363	738.354	38.888	0.4666	0.1088	0.	100.000	0.22148E-02
8.057	574.716	463.539	-55.005	-1.943	0.4466	0.1089	0.	92.786	0.
8.482	2662.237	2394.754	715.606	38.048	0.4239	0.1090	0.	100.000	0.21973E-02
8.907	563.538	441.042	-52.520	-2.028	0.4032	0.1092	0.	100.000	0.21813E-02
9.332	3009.582	2660.369	683.862	36.739	0.3891	0.1092	0.	100.000	0.21665E-02
9.757	548.024	409.069	-49.094	-2.160	0.3658	0.1093	0.	77.296	0.
10.182	3347.574	2906.432	654.178	35.346	0.3454	0.1093	0.	100.000	0.21530E-02
10.607	533.592	378.455	-45.873	-2.298	0.3228	0.1094	0.	70.695	0.
11.032	3676.870	3133.756	626.478	33.865	0.3027	0.1094	0.	100.000	0.21406E-02
11.457	520.197	349.100	-42.793	-2.443	0.2840	0.1094	0.	64.836	0.
11.882	3998.093	3343.092	600.635	32.291	0.2678	0.1094	0.	100.000	0.21294E-02
12.307	507.741	320.875	-39.928	-2.594	0.2500	0.1094	0.	59.629	0.
12.732	4311.798	3535.107	576.524	30.621	0.2345	0.1094	0.	100.000	0.21192E-02
13.157	496.128	293.661	-37.243	-2.751	0.2200	0.1094	0.	55.001	0.
13.582	4618.485	3710.398	554.044	28.852	0.2078	0.1094	0.	100.000	0.21101E-02
14.007	485.272	267.349	-34.705	-2.913	0.1966	0.1094	0.	50.889	0.
14.432	4918.602	3869.501	533.112	26.978	0.1878	0.1094	0.	100.000	0.20948E-02
14.857	475.097	241.850	-32.287	-3.080	0.1805	0.1094	0.	47.239	0.
15.282	5212.554	4012.897	513.661	25.000	0.1742	0.1094	0.	100.000	0.20896E-02
15.707	465.536	217.080	-29.965	-3.251	0.1688	0.1094	0.	44.005	0.
16.132	5500.706	4141.020	495.635	22.913	0.1643	0.1094	0.	100.000	0.20810E-02
16.557	456.527	192.969	-27.720	-3.425	0.1603	0.1094	0.	39.433	0.
16.982	5783.382	4254.261	478.994	20.718	0.1578	0.1094	0.	100.000	0.20776E-02
17.407	448.017	169.456	-25.536	-3.598	0.1558	0.1094	0.	35.761	0.
17.832	6015.151	4337.576	466.149	18.805	0.1542	0.1094	0.	100.000	0.20748E-02
18.257	441.266	150.264	-23.751	-3.742	0.1532	0.1094	0.	34.224	0.
18.682	6243.476	4410.980	454.227	16.818	0.1522	0.1094	0.		
19.107	434.800	131.420	-21.992	-3.883	0.1512	0.1094	0.		
19.532	6468.500	4474.646	443.217	14.757	0.1502	0.1094	0.		
19.957	428.596	112.899	-20.255	-4.020	0.1492	0.1094	0.		
20.382	6690.353	4528.737	433.107	12.627	0.1482	0.1094	0.		
20.807	422.632	94.680	-18.536	-4.152	0.1472	0.1094	0.		
21.232	6909.155	4573.405	423.889	10.430	0.1462	0.1094	0.		
21.657	416.884	76.742	-16.834	-4.275	0.1452	0.1094	0.		

TIME	RANGE X-DERIV	ALTITUDE Y-DERIV	VELOCITY V-DERIV	THETA TH-DERIV	MACH	KD	THRUST	WEIGHT DRAG	DENSITY PRESSURE
13.610	7125.013	4608.791	415.554	8.172	0.3783	0.1093	0.	100.000	0.20726E-02
14.132	411.335	59.067	-15.147	-4.369	0.3715	0.1093	0.	32.870	0.
	7338.026	4635.030	408.095	5.857				100.000	0.20709E-02
	405.965	41.641	-13.476	-4.492				31.687	0.
14.653	7548.282	4652.247	401.501	3.491	0.3655	0.1094	0.	100.000	0.20698E-02
	400.756	24.450	-11.825	-4.581				30.665	0.
15.174	7755.861	4660.562	395.763	1.083	0.3603	0.1094	0.	100.000	0.20693E-02
	395.692	7.483	-10.195	-4.655				29.796	0.
15.696	7960.834	4660.087	390.868	-1.359	0.3558	0.1094	0.	100.000	0.20693E-02
	390.758	-9.270	-8.590	-4.713				29.071	0.
16.121	8126.219	4653.264	387.488	-3.371	0.3528	0.1094	0.	100.000	0.20698E-02
	386.818	-22.788	-7.304	-4.747				28.581	0.
16.546	8289.941	4640.719	384.651	-5.396	0.3502	0.1095	0.	100.000	0.20706E-02
	382.946	-36.172	-6.042	-4.769				28.178	0.
16.972	8452.031	4622.509	382.344	-7.427	0.3480	0.1095	0.	100.000	0.20717E-02
	379.136	-49.424	-4.806	-4.779				27.860	0.
17.397	8612.511	4598.689	380.557	-9.460	0.3464	0.1095	0.	100.000	0.20732E-02
	375.382	-62.548	-3.601	-4.776				27.622	0.
17.823	8771.405	4569.313	379.275	-11.489	0.3452	0.1095	0.	100.000	0.20750E-02
	371.676	-75.543	-2.430	-4.761				27.463	0.
18.248	8928.732	4534.437	378.484	-13.509	0.3444	0.1095	0.	100.000	0.20772E-02
	368.013	-88.411	-1.296	-4.734				27.378	0.
18.673	9084.508	4494.113	378.167	-15.515	0.3441	0.1095	0.	100.000	0.20797E-02
	364.387	-101.153	-0.202	-4.695				27.366	0.
19.099	9238.750	4448.396	378.306	-17.502	0.3442	0.1095	0.	100.000	0.20826E-02
	360.793	-113.769	0.848	-4.645				27.424	0.
19.524	9351.468	4397.340	378.882	-19.465	0.3446	0.1095	0.	100.000	0.20858E-02
	357.227	-126.257	1.853	-4.585				27.549	0.
19.949	9542.674	4340.998	379.876	-21.401	0.3454	0.1095	0.	100.000	0.20894E-02
	353.682	-138.617	2.810	-4.516				27.740	0.
20.363	9688.182	4281.230	381.222	-23.253	0.3466	0.1095	0.	100.000	0.20931E-02
	350.255	-150.505	3.693	-4.441				27.985	0.
20.776	9832.276	4216.574	382.922	-25.072	0.3481	0.1095	0.	100.000	0.20972E-02
	346.841	-162.268	4.527	-4.359				28.288	0.
21.190	9974.962	4147.080	384.958	-26.856	0.3498	0.1095	0.	100.000	0.21016E-02
	343.437	-173.906	5.312	-4.270				28.647	0.
21.603	10116.241	4072.800	387.308	-28.603	0.3519	0.1095	0.	100.000	0.21063E-02
	340.041	-185.417	6.047	-4.177				29.060	0.
22.017	10256.118	3993.790	389.951	-30.309	0.3542	0.1094	0.	100.000	0.21113E-02
	336.649	-196.797	6.732	-4.080				29.524	0.
22.430	10394.593	3910.102	392.867	-31.975	0.3567	0.1094	0.	100.000	0.21166E-02
	333.260	-208.044	7.367	-3.979				30.039	0.
22.843	10531.667	3821.792	396.035	-33.599	0.3595	0.1094	0.	100.000	0.21223E-02
	329.870	-219.156	7.952	-3.876				30.602	0.
23.257	10667.339	3728.916	399.435	-35.180	0.3625	0.1094	0.	100.000	0.21282E-02
	326.478	-230.131	8.488	-3.771				31.211	0.
23.670	10801.608	3631.532	403.047	-36.717	0.3656	0.1094	0.	100.000	0.21344E-02
	323.083	-240.965	8.976	-3.665				31.866	0.
24.084	10934.472	3529.699	406.850	-38.210	0.3689	0.1094	0.	100.000	0.21410E-02
	319.683	-251.655	9.417	-3.559				32.564	0.
24.526	11075.200	3415.777	411.115	-39.761	0.3726	0.1093	0.	100.000	0.21489E-02
	316.034	-262.941	9.839	-3.466				33.357	0.
24.969	11214.311	3296.897	415.555	-41.261	0.3765	0.1093	0.	100.000	0.21559E-02
	312.377	-274.055	10.210	-3.334				34.196	0.

TIME	RANGE X-DERIV	ALTITUDE Y-DERIV	VELOCITY V-DERIV	THETA TH-DERIV	MACH	KD	THRUST	WEIGHT DRAG	DENSITY PRESSURE
25.412	11351.801	3173.134	420.148	-42.713	0.3805	0.1093	0.	100.000	0.21639E-02
	308.711	-284.995	10.532	-3.223				35.078	0.
25.855	11487.665	3044.567	424.873	-44.115	0.3846	0.1093	0.	100.000	0.21723E-02
	305.034	-295.756	10.807	-3.114				36.002	0.
26.297	11621.899	2911.276	429.711	-45.470	0.3888	0.1092	0.	100.000	0.21809E-02
	301.347	-306.335	11.037	-3.008				36.965	0.
26.740	11754.498	2773.342	434.640	-46.779	0.3931	0.1092	0.	100.000	0.21899E-02
	297.649	-316.729	11.225	-2.904				37.965	0.
27.183	11885.457	2630.848	439.644	-48.042	0.3974	0.1092	0.	100.000	0.21993E-02
	293.940	-326.934	11.372	-2.803				39.000	0.
27.626	12014.772	2483.878	444.704	-49.261	0.4018	0.1092	0.	100.000	0.22089E-02
	290.220	-336.947	11.480	-2.705				40.069	0.
28.068	12142.438	2332.518	449.804	-50.437	0.4062	0.1091	0.	100.000	0.22189E-02
	286.490	-346.766	11.553	-2.610				41.168	0.
28.511	12268.450	2176.854	454.928	-51.572	0.4106	0.1091	0.	100.000	0.22292E-02
	282.750	-356.388	11.591	-2.518				42.297	0.
29.006	12407.372	1997.831	460.669	-52.794	0.4155	0.1091	0.	100.000	0.22410E-02
	278.558	-366.907	11.596	-2.419				43.590	0.
29.501	12544.216	1813.663	466.402	-53.968	0.4204	0.1091	0.	100.000	0.22533E-02
	274.355	-377.174	11.563	-2.325				44.915	0.
29.996	12678.978	1624.476	472.110	-55.096	0.4253	0.1090	0.	100.000	0.22660E-02
	270.143	-387.183	11.496	-2.234				46.267	0.
30.491	12811.652	1430.399	477.778	-56.180	0.4301	0.1090	0.	100.000	0.22790E-02
	265.923	-396.934	11.397	-2.147				47.645	0.
30.986	12942.236	1231.561	483.388	-57.222	0.4348	0.1090	0.	100.000	0.22924E-02
	261.697	-406.422	11.268	-2.064				49.045	0.
31.481	13070.727	1028.090	488.928	-58.224	0.4395	0.1089	0.	100.000	0.23062E-02
	257.466	-415.647	11.112	-1.985				50.465	0.
31.976	13197.123	820.120	494.385	-59.188	0.4441	0.1089	0.	100.000	0.23204E-02
	253.233	-424.605	10.932	-1.910				51.902	0.
32.471	13321.423	607.781	499.747	-60.116	0.4486	0.1089	0.	100.000	0.23349E-02
	248.999	-433.297	10.728	-1.838				53.353	0.
32.966	13443.628	391.206	505.003	-61.008	0.4529	0.1089	0.	100.000	0.23498E-02
	244.766	-441.721	10.505	-1.769				54.816	0.
33.461	13563.738	170.528	510.143	-61.868	0.4572	0.1088	0.	100.000	0.23651E-02
	240.537	-449.875	10.263	-1.704				56.287	0.
33.790	13642.371	21.726	513.490	-62.421	0.4600	0.1088	0.	100.000	0.23794E-02
	237.731	-455.144	10.092	-1.662				57.269	0.
33.837	13653.700	-0.002	513.971	-62.500	0.4604	0.1088	0.	100.000	0.23799E-02
			END	OF TRAJECTRY					
33.837	13653.700	-0.002	513.971	-62.500	0.4604	0.1088	0.	100.000	0.23799E-02
	237.324	-455.898	10.067	-1.656				57.411	0.

TEA-2  
TRAJECTORY ERROR ANALYSIS \*\* TWO DEGREES OF FREEDOM

ANALYSIS \*\* DR. H.J. KOPP \* EXTENSION 72264 \* REPORT TO BE PUBLISHED  
PROGRAMMING \*\* MR. J.N. NIELSEN \* EXTENSION 73230

THIS PROGRAM SELECTS THE INTEGRATION STEP LENGTH SUCH THAT THE ERROR IN THE TOTAL RANGE IS LESS THAN A  
PRESCRIBED AMOUNT AND/OR THE ERROR IN ALTITUDE IS LESS THAN A PRESCRIBED AMOUNT. THE ERROR CRITERION USED FOR  
THIS TRAJECTORY WAS \*\*

THE ERROR IN TOTAL RANGE IS LESS THAN 0.50 PERCENT.

THE ABOVE CONDITION WAS SATISFIED, AND THE COMPUTED ERROR IN TOTAL RANGE IS EQUAL TO 0.20411938E-00 PERCENT.

FINAL ERROR ESTIMATES

\*\*\*\*  
RANGE 0.13653699E 05 RANGE ERROR 0.27869847E 02 ALTITUDE -0.16103294E-02 ALTITUDE ERROR 0.19756567E 02  
THETA -0.62500186E 02 THETA ERROR 0.36391161E-00 VELOCITY 0.51397064E 03 VELOCITY ERROR 0.74526225E 00

INITIAL CONDITIONS

\*\*\*\*  
RANGE -0. ALTITUDE -0. THETA 0.45000000E 02 VELOCITY 0.09999999E 04

TABLE OF ERROR ESTIMATES

TIME	RANGE ERROR		ALTITUDE ERROR		THETA ERROR		VELOCITY ERROR	
	RANGE	ALTITUDE	RANGE	ALTITUDE	THETA	VELOCITY	RANGE	ALTITUDE
0.42321443E 01	0.26622376E 04	0.79198267E 00	0.23947539E 04	0.61440352E 00	0.38047796E 02	0.71560609E 03	0.71560609E 03	0.70057453E-02
0.10482828E 02	0.57833844E 04	0.27059503E 01	0.42542616E 04	0.21146028E 01	0.20718350E 02	0.47899339E 03	0.47899339E 03	0.48066485E-01
0.15695586E 02	0.79608352E 04	0.37017895E 01	0.46600877E 04	0.26971755E 01	-0.13590061E 01	0.39086834E 03	0.39086834E 03	0.10064537E-00
0.19949489E 02	0.95426740E 04	0.48154643E 01	0.43409983E 04	0.33297788E 01	-0.21401435E 02	0.37987571E 03	0.37987571E 03	0.16588639E-00
0.24083638E 02	0.10934472E 05	0.72549541E 01	0.35296989E 04	0.52193458E 01	-0.38209875E 02	0.40685038E 03	0.40685038E 03	0.27014931E-00
0.28511017E 02	0.12268449E 05	0.13093567E 02	0.21768546E 04	0.97570217E 01	-0.51572245E 02	0.45492835E 03	0.45492835E 03	0.43775219E-00
0.33460953E 02	0.13563738E 05	0.27869847E 02	0.17052772E 03	0.19756567E 02	-0.61867693E 02	0.51014319E 03	0.51014319E 03	0.70454574E 00
0.33789781E 02	0.13642371E 05	0.27869847E 02	0.21728190E 02	0.19756567E 02	-0.62421049E 02	0.51348998E 03	0.51348998E 03	0.74526225E 00

IMPACT BETWEEN RANGE OF 0.13642371E 05 FEET AND 0.13664990E 05 FEET

IMPACT CENTER PREDICTED AT RANGE OF 0.13653699E 05 FEET AND ALTITUDE OF-0. FEET



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